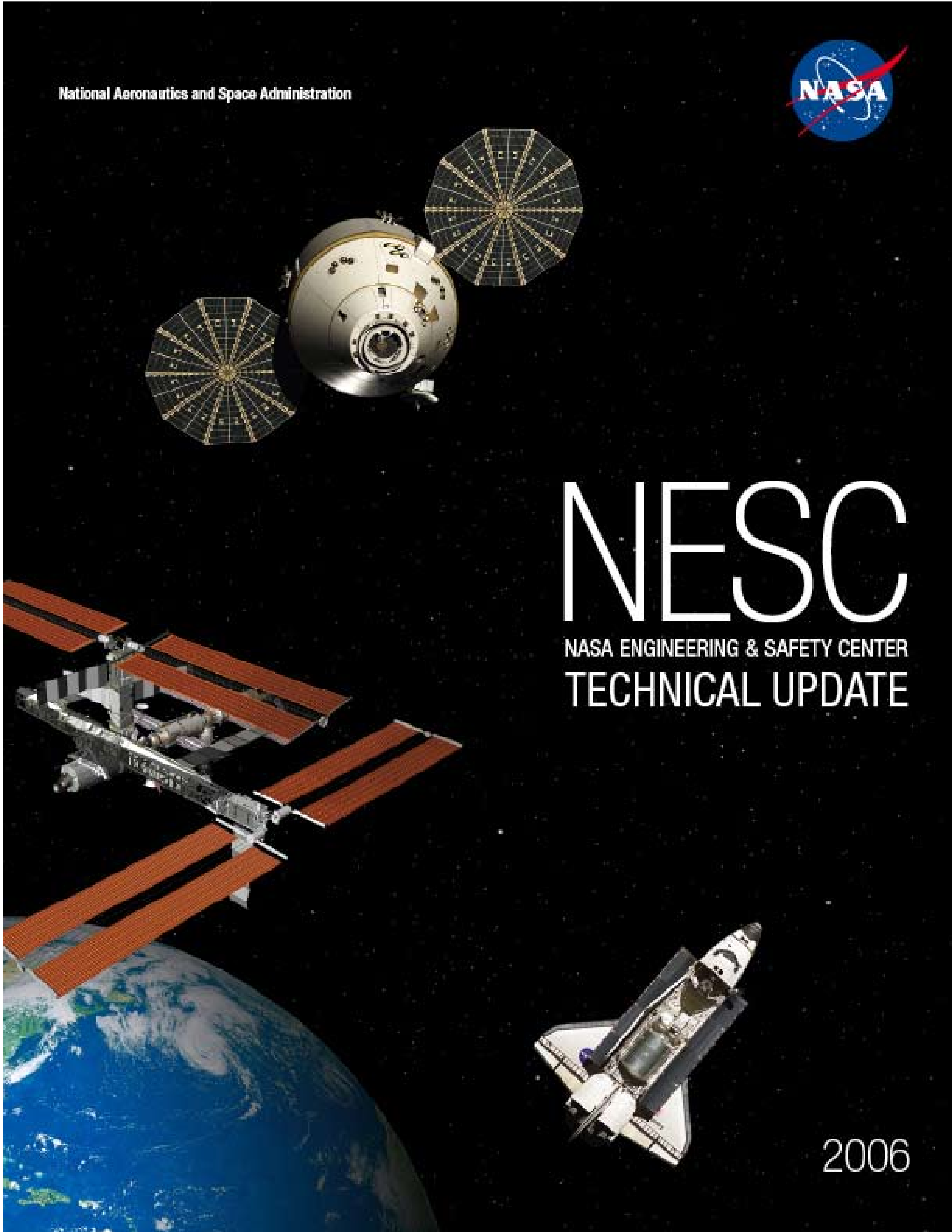
National Aeronautics and Space Administration



NESC

NASA ENGINEERING & SAFETY CENTER TECHNICAL UPDATE

2006

NASA

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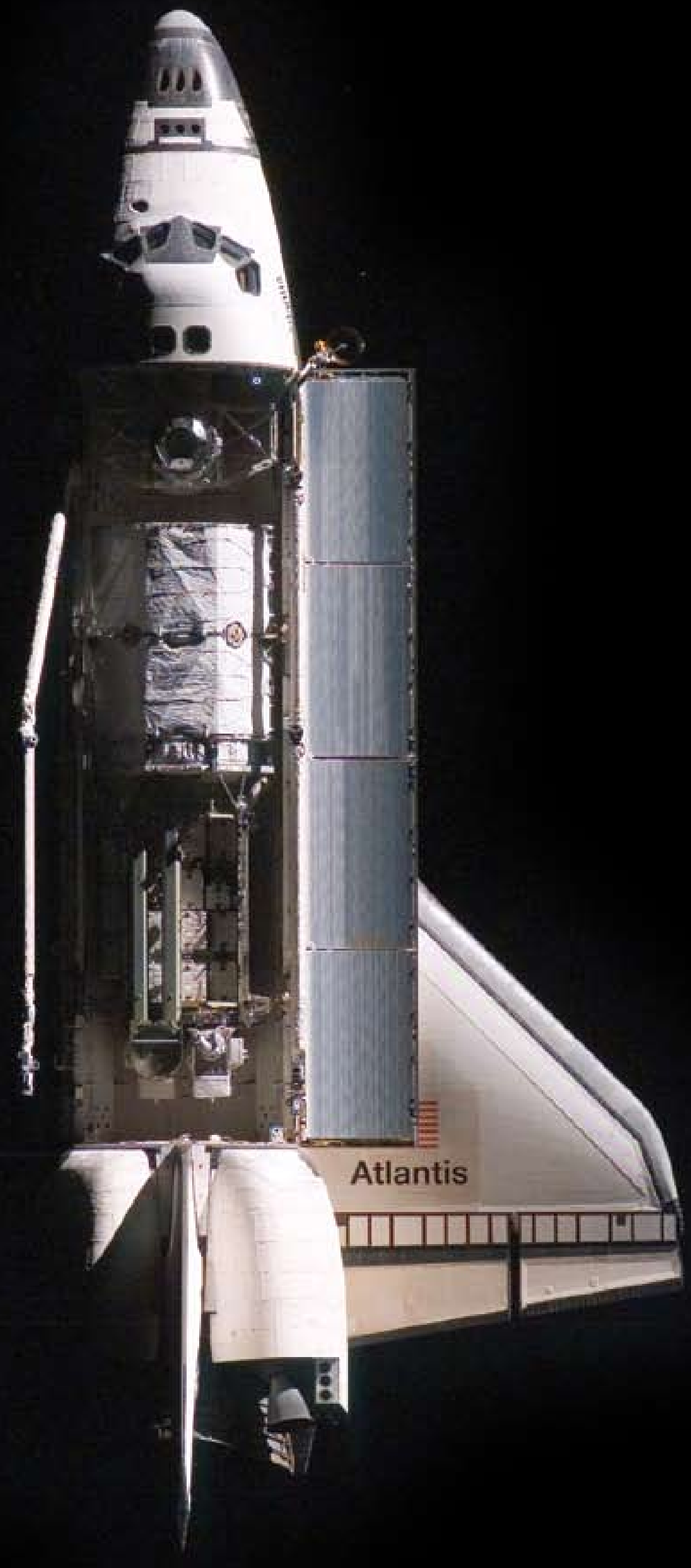


Overhead view of Atlantis taken September 11, 2006 from the International Space Station during the STS-115 mission.

Stakeholder Messages

Dr. Michael D. Griffin
NASA Administrator

I've found the NESC, because of its ability to work across NASA and to bring the greatest talent within the Agency to bear on problems of the most diverse nature, to be among the most valuable resources available to me as Administrator. The NESC efficiently concentrates resources where needed, yet employs the advantages of a distributed architecture to do so. It has been one of our real post-Columbia success stories.

Christopher J. Scolese
NASA Chief Engineer

The NESC, in its third year of operation, continues to offer a unique resource to NASA and other organizations. The unique ability of the NESC to bring together technical experts from across the Agency and the aerospace community has provided the expertise to resolve our most critical problems. The highest tribute one can provide to the NESC and its personnel is the recognition by their peers as reflected by the increase in requests, from all levels of the Agency, for their support in resolving problems, reviewing activities, and conducting special studies. These have ranged from detailed support of the Space Shuttle Program's flight activities, to addressing unique issues associated with CALIPSO, to the Smart Buyer Study for the Constellation Program. Some examples are provided in this Technical Update. Further recognition of the contributions that the NESC is making to NASA is the fact that graduates of the NESC are in senior positions within NASA — from engineering leadership on major projects up to Center Director. The NESC is more than a problem-solving organization. It is also an engine for improving the competence of our engineering workforce through the opportunity to work on challenging problems, through exposure to other organizations within NASA, and through its promulgation of lessons learned to the Agency. Lessons learned are provided in the technical reports and through the NESC Academy courses. This Technical Update highlights some of those lessons, so take the time to read this issue and reflect on how these lessons could help in your particular activity. In closing, the NESC has established itself as a reliable, credible and respected organization within the Agency and is an outstanding example of Engineering Excellence in practice.

Bryan D. O'Connor
NASA Chief Safety and Mission Assurance Officer

In its third year, the NESC continued to provide me (and other Agency leaders and decision makers) with outstanding independent technical information to support our decisions involving the safety and mission success of Agency missions. The many mission successes of this year are a testament in substantial part to the hard work and dedicated efforts of the many diverse members of the NESC. A great example was the "Smart Buyer" initiative. Here, the NESC was able to quickly assemble a team of experts to analyze options and trade-offs for the next generation space vehicles for the Exploration initiative, showing once again that the NESC is a most valuable and unique resource to the Agency as we make decisions on the path back to the Moon.

As the NASA Engineering and Safety Center (NESC) Leadership Team, we are proud to provide you with this Technical Update for 2006. In this update, we will present a cross-section of our technical activities, along with the broadly applicable lessons learned from our assessments. Sharing the knowledge gained from our efforts with the NASA technical community is an important goal for the NESC. In order to successfully provide value-added independent products to the Agency's high-risk programs and projects, we must rely on the expertise and resources at the NASA Centers and operate as a true One NASA organization. In the NESC Center Highlights pages of this update, we describe how multiple NASA Centers contributed to each of the NESC's technical efforts, and thus to the NASA mission.

During our third year of operation, the NESC has continued to support the Space Shuttle and International Space Station Programs, along with numerous robotic and science missions including Pluto New Horizons, Stardust and Phoenix. The year also marked a shift in our attention as we have become more actively engaged in the Constellation Program. We have conducted additional NESC Academy courses and continued to recognize engineering excellence through our NESC Honor Awards. In keeping with the model of the NESC, our team members continue to transition back to leadership positions at the Centers. The NESC periodically advertises for highly skilled and motivated individuals to join the NESC team and make a difference in the NASA Mission. Lastly, we hope that our technical update will be of value and that it provides a better understanding of the NESC Mission.

—NESC Leadership Team 2006

NESC Leadership Team – (left to right) Marc Hollander – former Manager of the Management and Technical Support Office, Dawn Schaible – Manager of the Systems Engineering Office, Ralph Roe – Director, Tim Wilson – Deputy Director, Kenneth Cameron – Deputy Director for Safety, Patricia Dunnington – Manager of the Management and Technical Support Office, and Dr. Charles Camarda – Deputy Director for Advanced Projects (not pictured).

NESC Overview

LaRC

Michael Kirsch, NESC Principal Engineer (foreground), presents the results of a study to the NESC Review Board (NRB). The NRB is a vital peer review process for the NESC.

Mission success starts with safety — safety starts with engineering excellence

One of the tenets of an effective safety philosophy is to provide an avenue for independent assessment of the technical aspects and risks of critical systems. This is the charge of the NESC, an organization dedicated to promoting safety through engineering excellence. A resource for the Agency, it is a valuable asset for the high-risk programs that NASA has always undertaken.

At the core of the NESC is an established knowledge base of technical specialists pulled from the ten NASA Centers and from a group of partner organizations external to the Agency. This ready group of engineering experts is organized into 15 discipline areas called Technical Discipline Teams (TDTs — formerly known as Super Problem Resolution Teams or SPRTs). TDT members are from NASA, industry, academia, and other government agencies. By drawing on the minds of leading scientists and engineers from across the country, the NESC consistently solves technical problems, deepens its knowledge base, strengthens its technical capabilities, and broadens its perspectives, thereby further executing its commitment to engineering excellence.

Components of the NESC

The structure of the NESC is based on maintaining a diverse and broad base of knowledge, keeping informed and engaged with each Center and the Agency's major programs, responding efficiently to requests for assistance, and retaining a high degree of independence. To achieve these goals, the NESC is organized into six offices:

NESC Discipline Experts assemble and provide leadership for the TDTs and are stewards for their disciplines.

NESC Chief Engineers provide insight into their Centers' programs and help to coordinate the facilities and resources of each Center when required to support NESC activities.

Principal Engineers use TDT members provided by the NESC Discipline Experts and resources arranged by the NESC Chief Engineers to lead technical reviews, assessments, tests, and analyses.

The Systems Engineering Office dispositions requests as they come in, performs proactive trending analysis and problem identification, and provides other integration and system engineering support.

The Management and Technical Support Office is the business arm of the NESC, taking care of the contracting, budgeting, and management of the NESC's infrastructure.

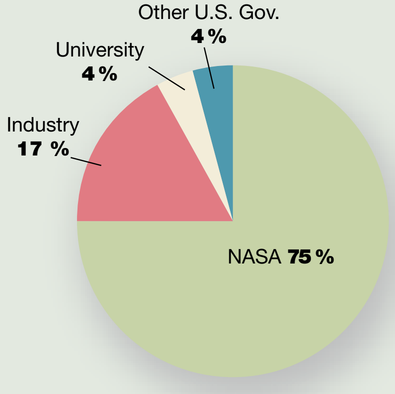
Under the leadership of the **Director's Office**, these five components come together to form the heart of the NESC — the NESC Review Board (NRB). The life cycle of every formal activity performed by the NESC requires approval of the NRB. The NRB brings a diversity of thought to the decision-making process. It is an amalgam of people representing different Centers, programs, and engineering backgrounds.

NESC Technical Discipline Teams (TDTs)

- Flight Sciences
- Fluids/Life Support/Thermal
- Guidance, Navigation & Control (GNC)
- Human Factors
- Human Space Flight Operations
- Loads and Dynamics
- Materials
- Mechanical Systems
- Nondestructive Evaluation (NDE)
- Power & Avionics
- Propulsion
- Robotic Missions
- Software
- Structures
- Systems Engineering

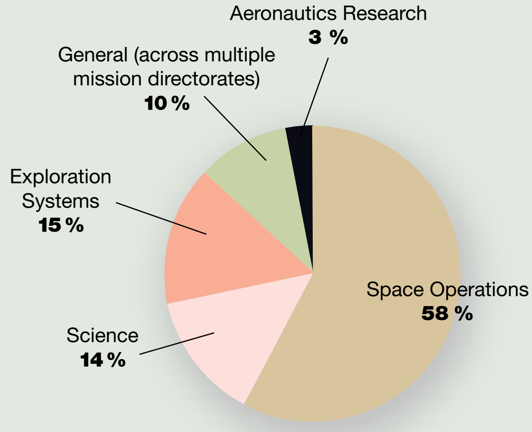
As a part of the NRB peer review process, Dr. Ivatury Raju, NESC Discipline Expert for Structures, examines a model of a Crew Exploration Vehicle crew module.

2006 Technical Discipline Team Composition



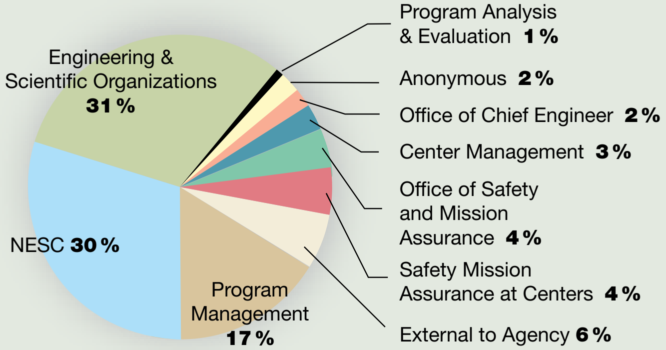
Accepted Requests By Mission Directorate: 166 Total

Cumulative as of November 1, 2006



Source of Accepted Requests: 166 Total

Cumulative as of November 1, 2006



Products

After an activity performed by the NESC has concluded, results are delivered to the stakeholders in the form of written engineering reports that include solution-driven preventative and corrective recommendations. The NESC strives to set the example for the Agency by providing full and appropriate documentation of every activity. Along with each report, lessons learned are communicated to Agency leadership and to engineers through avenues such as the Agency lessons learned system, the reports themselves, and this publication. In addition to acting on requests from outside of the NESC, another important function of the NESC is to engage in proactive investigations to identify and address potential concerns before they become major problems. To further this goal, the NESC is currently leading NASA's efforts for independent data mining and trend analysis. The NESC has established a Data Mining and Trending Working Group that includes representatives from all NASA Centers as well as external to the Agency.

An Independent Resource

The NESC is organized under the NASA Office of the Chief Engineer and is closely aligned with the NASA Office of Safety and Mission Assurance, so it is not in-line with any Program or Mission Directorate either from a budgetary or an organizational standpoint. The NESC is available not only to program/project managers, but to anyone associated with NASA's projects who requires independent testing, analysis, or assessment. By virtue of its distributed framework, access to the NESC is available through the Center NESC Chief Engineer or by emailing a request to nesc@nasa.gov There are approximately sixty NESC-badged employees, but through the TDTs, there are ten times that many people who participate in NESC activities. These matrixed employees are located at each Center and Headquarters and enjoy the benefits of working with and learning from the leaders in their fields.

technical accomplishments

STS-114 launches July 4, 2006

NESC Ice Mitigation Team Works to Reduce Ice Formation and Growth on External Tank

Problem: Potentially damaging ice can grow on components of the Space Shuttle's External Tank (ET) once it is filled with cryogenic hydrogen and oxygen. Areas along the liquid oxygen (LOX) feedline including the bellows and support brackets are susceptible to the formation of ice. Ice can also form in the ET/Orbiter umbilical area, intertank flange, and on the umbilical baggie material.

NESC Contributions:

Intertank Flange

To reduce ice buildup and release from the intertank flange area, the team has performed a series of cryogenic developmental tests on a simulated scale ET intertank flange to demonstrate the effectiveness of using Nanogel® insulating beads in reducing cryo-ingested nitrogen and subsequent ET foam loss. Test results are being shared with the Space Shuttle Program (SSP), and efforts are underway to perform the next level of tests on flight-like hardware. The NESC will provide recommendations to the SSP regarding Nanogel® bead characteristics for any upcoming SSP tests

MSFC

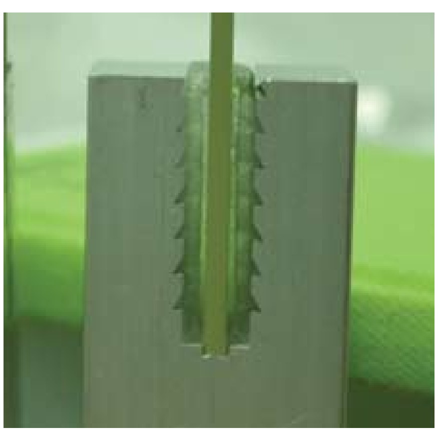
Glenn Durell (left) and Mike Ferrick (right) of the U.S. Army's Cold Regions Research & Engineering Laboratory, Hanover, N.H., examine a double lap shear test coupon coated with SILC.

Shuttle Ice Liberation Coating

A coating to reduce ice adhesion has been developed by the NESC team and has been tested on multiple substrate materials at temperatures down to -170ºF. Shuttle Ice Liberation Coating (SILC) reduces the ice adhesion strength substantially on all surfaces (75 to 100% reduction in adhesion strength) and could be applied to surfaces on the Space Shuttle that would benefit from early ice liberation. A patent has been applied for SILC.

Flexible Foam

A flexible polyimide foam segment to insulate the area between the LOX feedline bracket and the feedline has been developed that allows the bracket to articulate while preserving the integrity of the ET and feedline insulating foam and prevents the formation of ice in the gap of the bracket. At White Sands Test Facility, the team is testing a PolyuMAC version of the flexible foam. The flexible foam showed that the quantity of ice could be reduced to acceptable levels for the LOX feedline bracket. Performance may be increased with the enhancements such as the use of an customized foam segment shape and application of SILC. The team has also developed an in-situ installation technique that relies on vacuum bagging the foam segment, and then removing the bag, allowing the foam to expand in the joint.

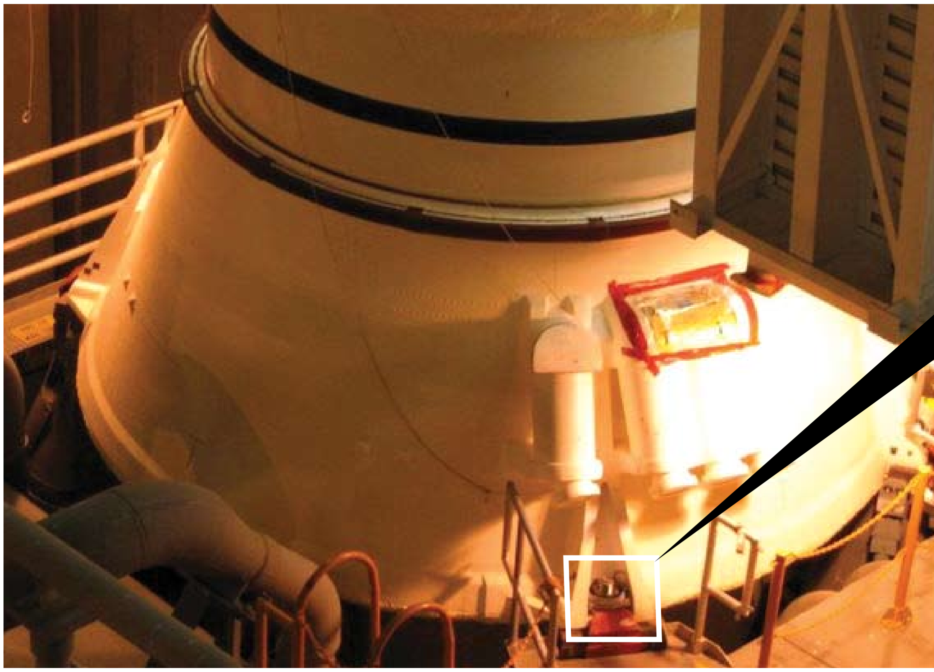


MSFC

SILC on aluminum specimen with ice in double lap shear fixture. The specimen is pulled from the fixture to measure ice adhesion.

WSTF

Vacuum-bagged flexible foam being inserted into a test fixture representative of the ET LOX feedline bracket gap.



Photos KSC

(Above) Test fixture with frangible HDP stud nut. Pyrotechnic devices are visible on either side of the nut. (Left) Location of one of four HDP stud nuts on the aft skirt of an SRB.

Space Shuttle Solid Rocket Booster Holddown Post Stud Hang-Up Root Cause Analysis

Problem: Solid Rocket Booster (SRB) stud hang-ups have occurred over the life of the Space Shuttle Program. The SRBs are bolted to the Mobile Launch Platform by a Holddown Post (HDP) system. At the time of launch, these bolt studs are designed to quickly exit into the HDP allowing the Space Shuttle to liftoff. A stud hang-up at liftoff can increase loads at the SRB/External Tank attach points.

NESC Contribution: The NESC undertook an extensive hardware test program to aid in determining root cause. This included development of a high fidelity stud and frangible nut model that was calibrated with data from the test project. The NESC found that a number of often violent factors work to slow or interrupt the stud's descent and clearance from the SRB. The cause of stud hang-ups was determined to be a combination of contributing factors including: frangible nut pyrotechnic firing skew, nut half recontact, plunger seating and frangible link breakage, debris interaction, bore hole contact, frictional forces from the plunger, and movement of the SRB aft skirt prior to full stud ejection. At launch, the cumulative result of these factors' individual effects on the stud, most of which are almost always in play but take place at variable levels of intensity, add up to slow down the stud's descent enough that a hang-up occurs. Extensive testing, modeling and simulation were used to arrive at this conclusion. The Space Shuttle SRB Project can now work toward modifications that reduce the number of these unwanted occurrences.

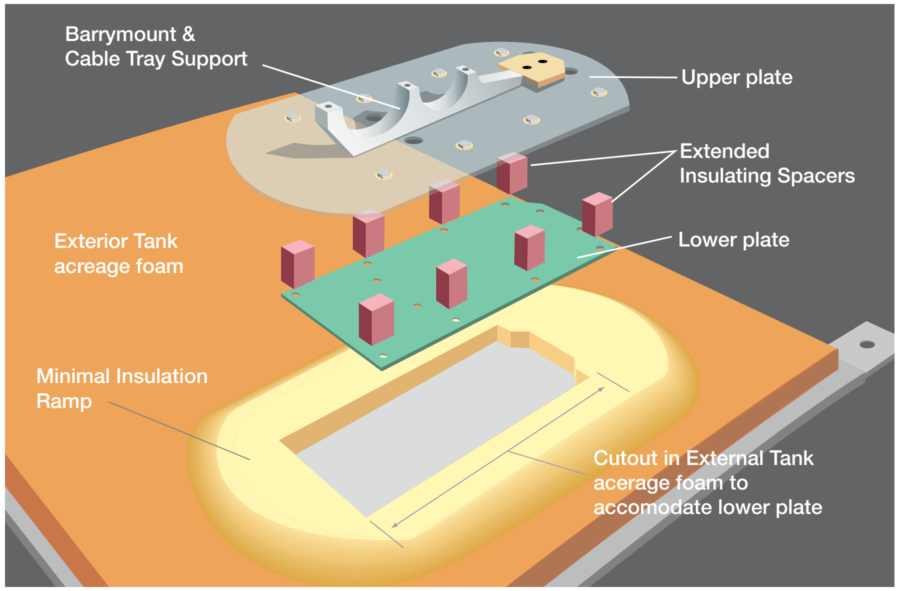
Leslie Curtis, NESC Back-up Principal Engineer and Peggy Ritchie, Senior Aerospace Inspector with United Space Alliance performing borescope inspection of holddown post hardware after a stud hang-up occurred during NESC testing at KSC.

Lessons Learned: Testing that includes firing pyrotechnics produces its own set of problems. Pyrotechnic devices produce large quantities of smoke that will interfere with photographic analysis unless smoke mitigation steps are taken. Pyrotechnic devices function very quickly and require special instrumentation to measure pyrotechnic explosion timing. Accelerometers may perform poorly in a blast environment due to shock and reverberation from the initial blast.

External Tank (ET) Liquid Hydrogen (LH2) Tank Ice/Frost Ramp (IFR) Design Modification

Problem: Foam and ice debris can be shed from the External Tank (ET) Liquid Hydrogen (LH2) Tank Ice/Frost Ramps (IFRs) and pose an impact hazard to the Orbiter on ascent. The IFRs are aerodynamically shaped sections of insulating foam that are molded around the brackets that attach the gaseous oxygen and hydrogen repressurization lines and cable trays to the ET.

NESC Contribution: The NESC pursued an independent effort directed at a mid-term redesign of the LH2 IFRs to minimize the debris potential to the Orbiter. This approach supplemented the ET Project's pursuit of an immediate-term modification of the existing LH2 IFRs. The goal of the NESC effort was to develop retrofit bracket design that ensured no surface temperature was less than 32 degrees Fahrenheit (°F) through the prelaunch countdown and would survive ascent thermal and structural loading. The concept selected for investigation, seen below, was a thermally-passive titanium bracket consisting if an exposed upper plate and bracket which maximized the surface area to absorb heat from the ambient air while minimizing the embedded cross section which is in contact with the LH2 tank. The NESC design minimizes the embedded cross section by isolating the exposed section from the colder surfaces of the LH2 tank by means of thermally resistant spacers attached to an embedded lower plate that is attached to the tank surface.



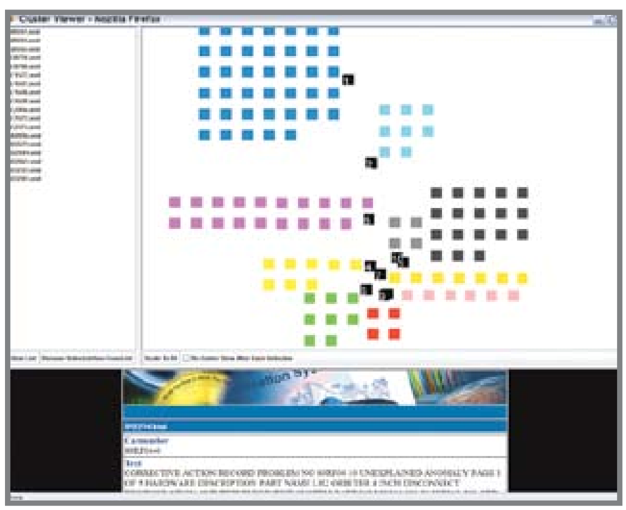
LaRC

The knowledge gained from the independent NESC investigation significantly influenced and facilitated the ET Project's efforts at developing bracket redesign concepts to replace the interim modifications to the existing LH2 IFRs.

NASA Engineering and Safety Center (NESC) Data Mining and Trending Working Group

The NESC is currently leading the Agency's efforts to perform independent data mining and trend analysis to identify unknown indicators of future problems. One of the NESC's goals is to perform independent analyses within programs and across programs, while not duplicating the program-specific trending efforts. Through workshops, monthly telecons, and training, the NESC has developed working relationships with data mining and statistical experts within academia, industry, and other government agencies. The NESC's collaboration with other organizations has enabled sharing of ideas, particularly regarding methodology and lessons learned.

The NESC-led Data Mining and Trending Working Group includes representatives from all NASA Centers as well as external experts from organizations such as the Federal Aviation Administration, the Department of Homeland Security, the National Transportation Safety Board, and the Institute of Nuclear Power Operations. This group is assisting NASA organizations in strengthening trending activities for the Agency's programs and projects. This is being accomplished in part by developing a data mining toolbox including tools such as the commercial data mining software, SAS, as well as a clustering tool under development by Ames Research Center, the Recurring Anomaly Detection System (ReADS). Mentoring activities and formal training are ongoing. This group also provides a forum to enhance communications across the Agency in the areas of data mining, trending, and statistics by sharing ideas, methods, technologies, processes, tools, and lessons learned.



ARC

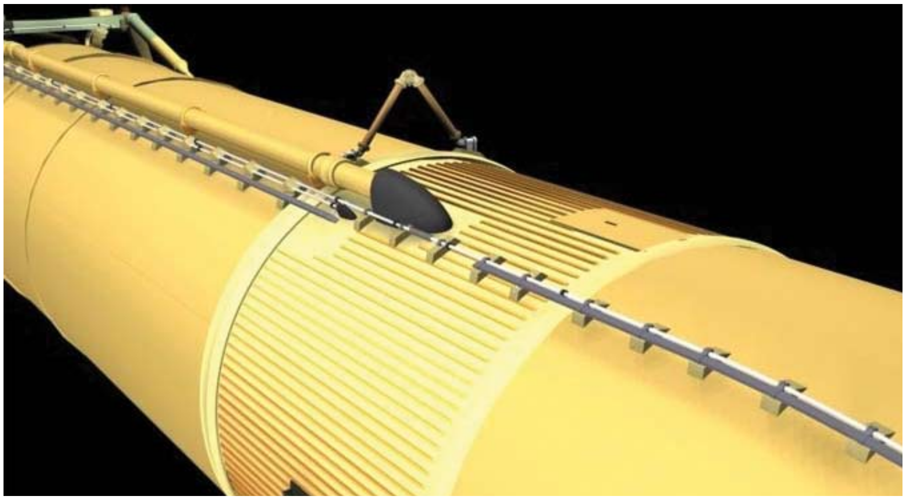
Recurring Anomaly Detection System (ReADS) display of problem report clusters. Clusters of seemingly disparate problems may indicate a common problem.

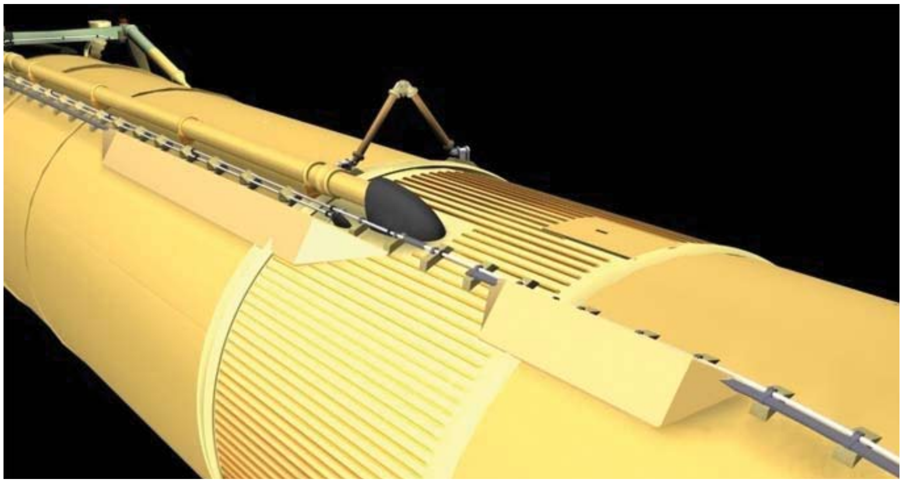
External Tank Protuberance Air Load (PAL) Ramp Removal Feasibility Independent Assessment

Problem: In August, 2005 the Space Shuttle Program's (SSP) External Tank (ET) Project initiated a Protuberance Air Load (PAL) Ramp Removal / No PAL Ramp ET design assessment. PAL Ramp removal required detailed test and analysis to certify the new design for flight. A team of experts in unsteady aerodynamics, loads and structural dynamics to support the re-design activity. Subsequently the SSP finalized the removal of the PAL Ramps on ET-119 for STS-121. The NESC team was directed to provide an independent assessment of the adequacy of the SSP's certification of this new Shuttle Launch Vehicle configuration.

NESC Contribution: The NESC team served as a technical consultant during SSP-sponsored test and analysis activities conducted to certify the no PAL Ramp Shuttle Launch Vehicle configuration. This team of experts provided detailed insight by real-time participation in SSP PAL Ramp removal team activities, data package, reviews, and design reviews. The NESC team was an active participant in the planning and conducting of the SSP sponsored wind tunnel test program to define certification loads, the evaluation of the loads and stress results and the definition of the certification design load environments including the ET Critical Design Review and Design Certification Review. The initial wind tunnel test derived loads significantly exceeded the preliminary design loads, in part due to unnecessary conservatism. The NESC assessed the dynamic test data processing and recommended and implemented alternate industry standard methods for analysis which improved prediction of a realistic dynamic load environment. The NESC team continued to evaluate the STS-121 and STS-115 flight data which demonstrated the acceptable load environment for the No-PAL Ramp ET configuration.

The SSP approached the redesign with a success oriented plan which required the SSP to analytically determine design certification loads prior to validation with actual wind tunnel testing. To meet near term schedule milestones and accommodate facility availability, testing was conducted at a smaller, less capable tunnel than that originally planned, which reduced the number of measurements and compromised the ability to gather all relevant test conditions. The wind tunnel test results did not correlate well with the pre-test certification loads. The nature and limitations of the test data base created a post-processing challenge which required extrapolation and special processing of the results to define a conservative certification loads update. Iterations were required to finalize the certification database for the STS-121 flight.





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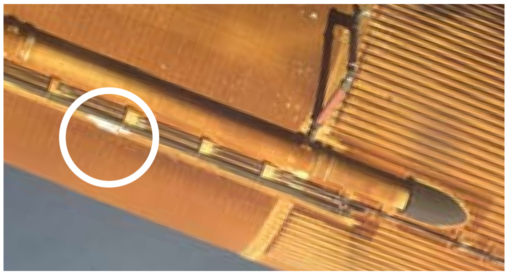

JSC

Rendering of the redesigned ET without PAL Ramp that was successfully flown on STS-121 and STS-115 (Top). ET with PAL Ramp (Middle). Photo taken from the ISS (Bottom) shows briefcase-size foam loss from the PAL Ramp on STS-114.

STS-121 flight data acceleration measurements confirmed that the cable tray loads were well within the design environment and not significantly impacted by the PAL Ramp removal indicating that the driving load for the hardware was indeed the base vibration and not the unsteady aerodynamic environment.

Lessons Learned: Facility capabilities often limit the ability to verify expected flight environments. These limitations need to be considered in establishing the certification approach. Flight data is invaluable when assessing complex environments.

NESC-Sponsored Orbiter Infrared Observation During STS-121 Entry

Problem: The NESC (in coordination with Langley Research Center Fundamental Hypersonics) sponsored the High Altitude Observation Aircraft (HALO II) to capture Orbiter surface temperature distributions using infrared (IR) camera observation of Discovery's entry during the STS-121 mission. HALO II was flown in conjunction with other aircraft (NASA WAVE and Navy Cast Glance) — sponsored by the Space Shuttle Program — to demonstrate capability. The primary objective associated with HALO II was to demonstrate the entry imaging capability by obtaining spatially resolved, calibrated (multi-spectral), thermal imagery of the Orbiter underside during or after Boundary Layer Transition (BLT) to turbulent flow. Protruding gap fillers identified while Discovery was in orbit provided an opportunity to characterize the effectiveness of these as BLT initiators.

NESC Contribution: The HALO II acquired Discovery during entry flight on July 17, 2006 via a Long Wave Infrared (LWIR) acquisition camera. Discovery was manually tracked and approximately 400 seconds of total data collection was recorded **(see Fig. 1)**. These HALO II observations encompassed the Mach 10 to 7 entry flight regime. Based on Orbiter surface thermocouple measurements, complete lower surface BLT occurred at approximately Mach 7.2. Additionally, a gap filler protruding just forward of the external tank umbilical door caused a localized early BLT that was captured by the LWIR entry imagery as a classic turbulent wedge downstream of the gap filler site, evident in **Fig. 1** and in the Cast Glance image using a Near Infrared (NIR) detector **(Fig. 3)**.

The STS-121 HALO II observations achieved the primary objectives by demonstrating that valuable entry BLT information can be derived via aircraft based imaging. Entry infrared imaging during STS-121 demonstrated capability to acquire and track the Orbiter during entry flight and differentiate between laminar and turbulent flow regions on the Orbiter lower surface. However, during STS-121 the Medium Wave Infrared (MWIR) camera images became saturated **(see Fig. 2)**, compromising the potential to derive quantitative results from these multi-spectral observations. Based on the HALO II and Cast Glance system performance during STS-121, entry infrared imaging shows promise for providing quantitative surface temperature measurements with sufficient resolution to resolve laminar–to-turbulent transition boundaries on the windward surface of the Orbiter.

The Space Shuttle Program has continued this effort with observations on STS-115 and planned observations for STS-116.

Lessons Learned: Entry infrared imaging techniques using aircraft-based systems can provide quantitative surface temperature data collection. In order to fully achieve this objective and maximize the data return, the entry trajectory and corresponding dispersions must be fully understood and accounted for in preflight planning and operational flexibility. To mitigate saturation issues, radiance models used to determine appropriate detector gains and filters settings must be better characterized. Wide Field of View (WFOV) optics are necessary to capture the Orbiter as it breaks horizon. Because of the uncertainty in the actual Orbiter BLT time for any given entry, multiple aircraft are required to ensure the targeted data are collected.

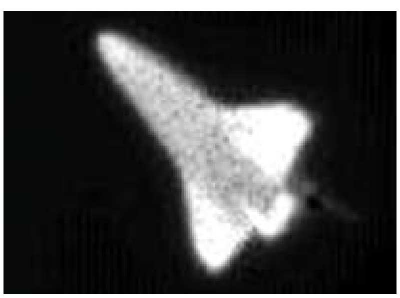

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Fig.1 HALO II STS-121 LWIR Image

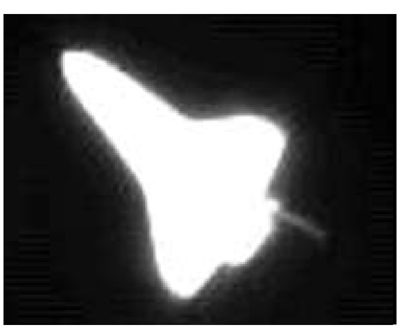

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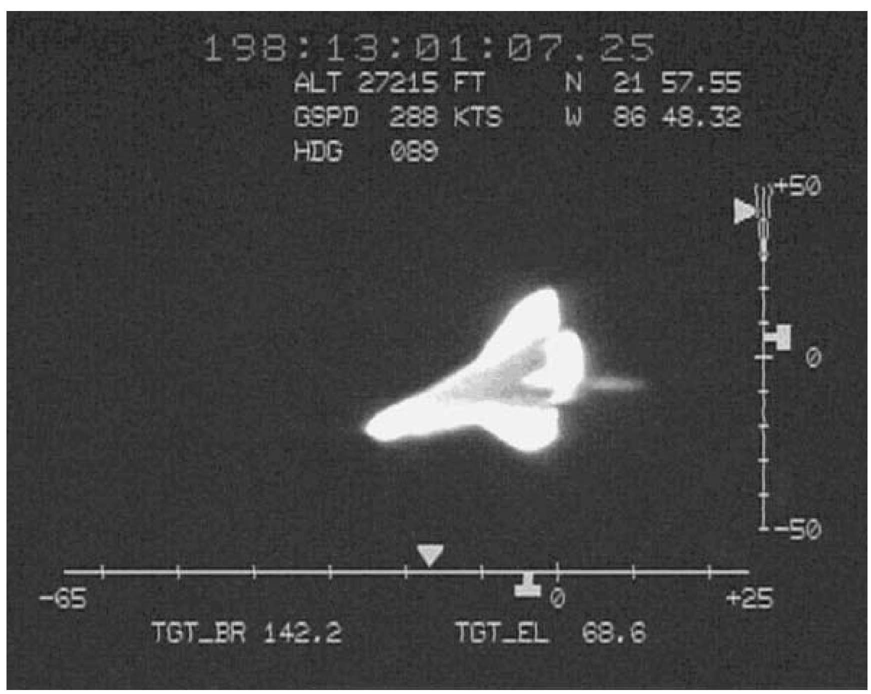
Fig. 2 HALO II STS-121 MWIR Image

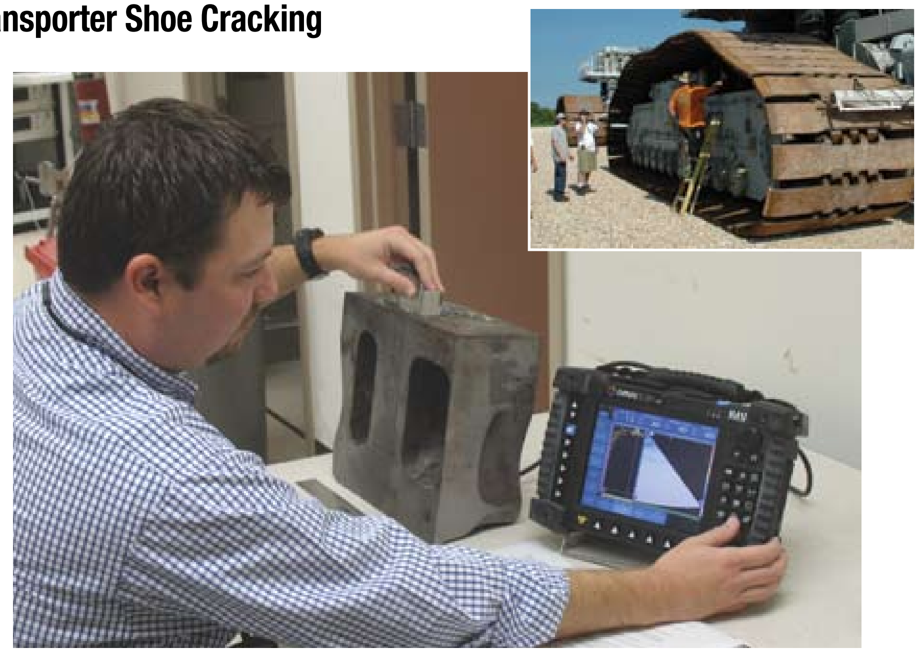


USN

Fig. 3 Cast Glance Image of STS-121

Kennedy Space Center Crawler Transporter Shoe Cracking

Problem: While transporting a mobile launch platform, one of the shoes on the KSC Crawler Transporter (CT) cracked and failed. The shoe was relatively new with low mileage as all CT shoes were replaced prior to the STS-114. A shoe failure during roll-out increases the exposure of the vehicle to the possibility of damage from lightening and is a potential hazard to ground personnel while repairs are made. Metallurgical analysis of the failed shoe showed that the crack initiated at an internal shrinkage void and then rapidly propagated through a large region of weaker material containing slag inclusion particles. Fabrication records indicated that the failed shoe was a "last pour" during the casting process. The NESC Nondestructive Evaluation (NDE) TDT was asked to review the near-term NDE efforts at KSC to inspect the CT shoes and to evaluate phased-array ultrasonic methods as an improved technique for longer-term inspection of the shoes.



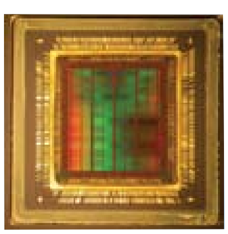
PHOTOS/KSC

Jeff Leak of the NDE TDT at NASA MSFC uses a phased array ultrasonic system to image simulated flaws in a crawler transporter shoe calibration standard. (Inset) KSC Crawler.

NESC Contribution: The NESC NDE TDT reviewed the near-term NDE efforts of KSC, USA, and Wyle personnel to inspect the CT shoes. These efforts included reviewing NDE documentation from the manufacturer, applying visual borescope and magnetic particle methods to all CT shoes, and applying conventional ultrasonic and high energy radiographic methods to selected spare shoes focusing on other "last pour" shoes. Additionally, KSC initiated an investigation of the applicability of modal testing methods to detect defects and damage in shoes. The NDE TDT provided concurrence with these efforts and actively participated in the review and analysis of test results. In particular, the NESC funded the high energy radiographic testing and provided modeling and analysis support for the testing effort. A smaller surface crack was found in a second CT shoe through the use of magnetic particle testing, but the radiographic testing did not indicate any regions of slag inclusions in the selected set of spare "last pour" shoes. Additionally, the NDE TDT demonstrated the capability of phased array ultrasonic methods on CT shoe specimen with simulated flaws. The phased array ultrasonic test (UT) method offers the advantages of more readily inspecting beneath the curved surface of the shoes and faster inspection times as compared to conventional single element ultrasonic transducers. A phased array UT inspection procedure has been developed and training for inspectors at KSC is planned. The improved phased array UT method will then be used to inspect the CT shoes to ensure that no additional casting flaws remain.

Field Programmable Gate Array Risk Reduction and Programmed Antifuse Reliability Evaluation

Problem: Multiple projects across the Agency are currently or will soon use 0.25-micron or 0.15- micron technology Radiation Tolerant (RT) Field Programmable Gate Arrays (FPGAs) to implement digital circuitry for flight applications. They offer significant advantages over older technologies previous versions in terms of capacity and capability. However, field failures in 2003 identified problems on a SX-S series part. At that time, many NASA applications using the SX-S were under development, causing significant cost impacts and higher mission risks. In response to these failures, the FPGA manufacturer instituted device foundry changes and antifuse programming algorithm changes.



NASA/OLD

RTAX-S FPGA showing package cavity, die, and wire bonds.

NESC Contribution: The NESC sponsored evaluation studies of the SX-S series part changes. Early test results indicate improved SX-S reliability. The NESC is also sponsoring reliability evaluation and risk reduction testing of the new RTAX-S parts with the goal of accelerating the detection of any potential problems. The RTAX-S provides greater capability and improved resistance to electrostatic discharge over the SX-S series parts. An NESC Agency-wide team is engaged to review results. Overall, the results from the NESC-sponsored SX-S and RTAX-S testing will benefit NASA by reducing risk through identifying problems (if any) early enough to allow projects to more effectively resolve them.

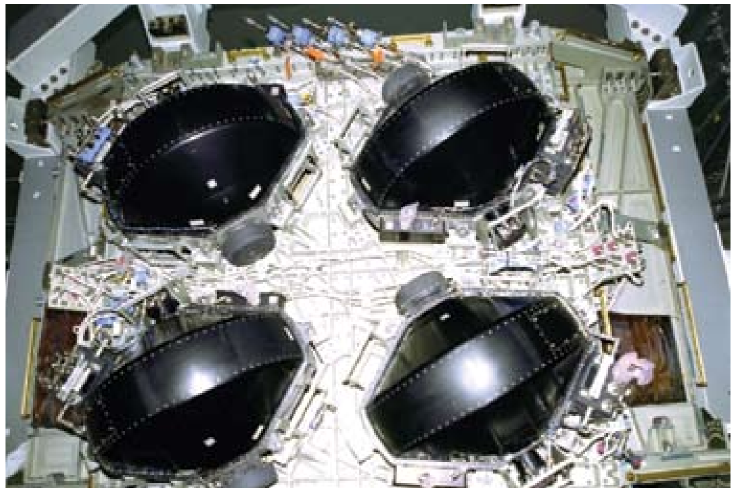
Lesson: Evaluation of complex parts under higher stress conditions than typically seen in user applications is important to detect potential problems and to establish limits and margins of the devices.

Control Moment Gyro-1 (CMG-1) Root Cause Analysis

Problem: The International Space Station (ISS) has four Control Moment Gyros (CMGs) that maintain attitude control. After operating nominally for 1.5 years, ISS CMG-1 failed on June 8, 2002. An ISS Root Cause Investigation Team (RCIT) was formed by the ISS Program in an attempt to understand the failure at that time.

After the failed unit was retrieved during STS-114 in August 2005, the ISS Program Manager reactivated the RCIT and requested the NESC's involvement to investigate and analyze the root cause(s) of the CMG-1 failure. The ISS RCIT conducted a rigorous investigation of the failure, which included detailed study of the failed bearing components, metrology of the non-failed bearing and the inner gimbal structure, thermal effects on bearing alignment, structural capability of the retainer, and condition of the lubrication system.

NESC Contribution: The NESC team reviewed the telemetry data from the failure event and other relevant operational data on the CMGs; reviewed and concurred on the RCIT disassembly procedures; reviewed RCIT inspection and test results and fault tree; reviewed CMG design; and supported and consulted with the NESC Guidance, Navigation & Control TDT and the ISS RCIT.



NASA

CMG-1 through CMG-4 mounted in the ISS Z1 truss with shroud removed.

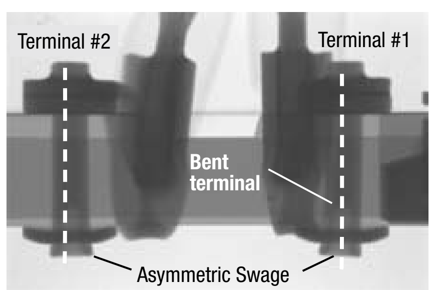
The NESC team's findings, observations, and recommendations were derived from two primary sources including the data and test results generated by the thorough ISS RCIT investigation and a detailed dynamic bearing analysis using the ADORE software. The NESC analysis evaluated the possibility of excessive retainer forces and the effect of race out-of-roundness, supporting analyses to strengthen the argument that failure of the pre-load system was the most probable cause of failure, and inspected/requested inspection of key components.

The NESC team concluded that although the analysis of existing data does not permit a single root cause to be positively determined, the most probable cause of the failure is loss of bearing pre-load due to binding of the outer race or races, stick-slip of the pre-load spring, and misalignment resulting from out-of-flat gimbal covers and the transient thermal conditions. The NESC team developed 20 recommendations in three general categories: bearing system design, safety, and orbital operational procedures.

Space Shuttle Engine Cutoff Sensor Anomaly and Reliability Investigation

Problem: The NESC was part of a team to determine the root cause of the anomalous behavior observed in the Space Shuttle Engine Cut-Off (ECO) sensor system during ET tanking tests and launch attempts on STS-114. A theory was developed that would explain how a sensor could show an apparent failure on first exposure to liquid hydrogen (LH2), but show no indication of anomalous behavior when returned to ambient temperature or on subsequent exposure to LH2.

NESC Contribution: The NESC team performed cryogenic cycling of 50 fully instrumented flight grade sensors between ambient and LH2 temperatures to determine the validity of the theory. Both nondestructive and destructive physical analysis techniques were employed to characterize a limited number of the sensors. All 50 sensors behaved nominally, and there were no measurable indications of faulty or changing electrical performance during or as a result of cryogenic cycling. However, nondestructive and destructive physical analysis indicate a number of issues with the material selection and process variability used in the fabrication of a swaged circuit board connection that could be highly sensitive to human factors in the assembly process and result in lot-to-lot variability. The nondestructive x-ray techniques for analysis of the sensor's swage connections, developed as part of this assessment, became the basis for the techniques used by the ET Project to evaluate replacement sensors for the ET-119.



GSFC

Manufacturing issues in an ECO sensor electrical terminal connections are visible in this x-ray image.

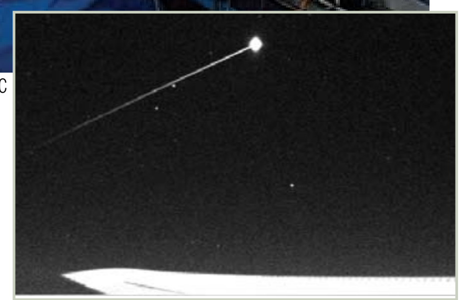
Lessons Learned: During the assessment, the NESC team became aware of a well intentioned practice by the ET manufacturer of removing sensors if they showed a greater than 2 ohm resistance shift. However, since these sensors had not exceeded the allowable limits, they were not considered failures, and were not fully destructively analyzed. The result was a short term improvement in the quality of the sensors delivered in the tanks at the expense of masking manufacturing defects which resulted in an overall reduction in sensor reliability.

NESC Sponsored StarDust Entry Observation Campaign

Problem: Existing aerodynamic, aerothermodynamic, and thermal protection system material response models have not been fully assessed against actual reentry data.

NESC Contribution: As the Stardust Sample Return Capsule (SRC) entered the Earth's atmosphere at 12.8 km/s, the fastest man-made object to traverse our atmosphere, an ARC-led NESC-sponsored team of researchers imaged the event aboard the NASA DC-8 airborne observatory. With the SRC not having any on-board flight instrumentation, the NESC sponsored data are the only time resolved record of the performance of the entry system. The radiative signals from the SRC and surrounding shock layer gasses were measured by 15 of 18 instruments that had various combinations of spectral range, spectral resolution, and temporal resolution. The data were assessed to be of very good quality and sufficient to address all observation objectives: absolute radiance, spectral resolution of shock layer emission, and wake train evolution. Analysis of these observation data and the recovered SRC heatshield will provide an assessment of the fidelity of the models and ground tests used to design the SRC. This assessment directly supports the Exploration Systems initiative in that these models and tests are being used in the design of the Crew Exploration Vehicle.

ARC



Investigator Michael Winter (University of Stuttgart) fine-tuning slit spectrometer with assistance from Principal Investigator Peter Jenniskens of the Search for Extraterrestrial Intelligence Institute. SRC entry visible (right) above wing of NASA's DC-8 Airborne Laboratory.

Lesson Learned: Ground photography of the entry event was an invaluable aide to trajectory reconstruction. These supplemental photographs to the imagery obtained aboard the aircraft provided an effective stereoscopic view of the entry thereby enabling trajectory reconstruction in the hypersonic regime prior to radar tracking.

Atlas V Tank Failure Investigation

Problem: The Atlas V first-stage fuel tank qualification test article failed catastrophically during hydrostatic testing, revealing a flaw in the attachment of internal ring stiffeners leading to localized cracking that over time and repeated load that could lead to tank structural failure. Internal borescope inspection of the particular tank to be used for the Pluto/New Horizons launch vehicle did not reveal the presence of any such cracks, however other tanks in the inventory did have such cracks.

NESC Contribution: The NESC was requested to participate in the failure analyses and provide a risk assessment for using the planned tank for the Pluto/New Horizons mission. The NESC conducted independent materials testing of the first-stage tank aluminum to define the local anisotropy contribution to the cracking, determine the minimum detectable flaw size, and crack propagation characteristics. In addition, the NESC performed detailed local iso-grid structural finite-element modeling to verify the contractor's tank-level finite element modeling assumptions, and advised the Launch Services Program and the contractor on local/global and nonlinear structural finite element analysis methods.

Based on these analyses, the NESC provided the Program with a risk rationale for use of the first-stage tank. The rationale for increased risk was relative to accepted engineering structural qualification practices, development of correlated mathematical models for qualified structure, and the development of flight rationale based on correlated mathematical models.

(Right) Atlas V launch vehicle Pluto/New Horizons satellite

NASA

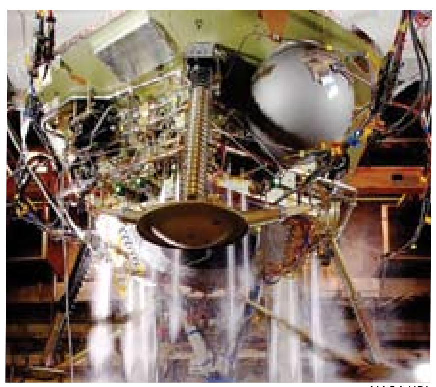
NASA/JPL

The Phoenix Mars Mission satellite being prepared for an August 2007 launch.

Phoenix Mars Mission Thruster Valve Leak Analysis

Problem: The Project performed a hot-fire test to assess performance of the descent propulsion system and any interactions with the control system, showed that some of the thrusters leaked. The effort to identify the most probable cause of the thruster valve leak had been comprehensive and methodical.

NESC Contribution: The NESC was requested to provide an independent assessment of the problem, the likely causes, and the Project's plans for mitigation. Following detailed briefings from the Project the NESC team formulated recommendations for additional test/analysis to support the root cause identification process. The NESC also evaluated the performance of the Guidance, Navigation and Control (GNC) system to deliver the lander safely in the face of various leakage scenarios. The NESC team concluded that the Project had properly evaluated the risks, performed proper root cause analysis, and had a robust GNC design to accommodate any reasonable leakage scenarios.



NASA/JPL

Hot fire test of Phoenix Mars Mission descent propulsion system thrusters.

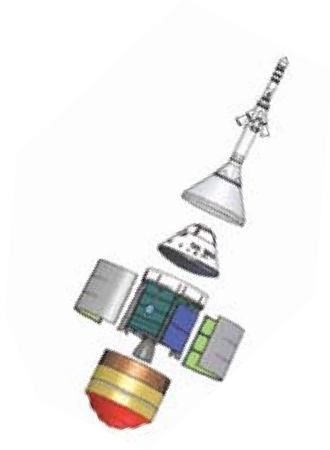
More specifically, the NESC found that absent a definitive root cause, there was reasonable evidence of limited valve degradation behavior. They also found that by implementing a strategy of evaluating terminal descent control cases, the Project is showing, through detailed Monte Carlo analysis, that adequate margins exist in the control of the spacecraft during descent.

Phoenix Mars Mission Structural Safety Margins Analysis

Problem: The Phoenix Mars Mission will use many components of a spacecraft originally built for the 2001 Mars Lander, which was kept in storage after that mission was cancelled. Phoenix inherited its flight system from the Mars01 Project. Phoenix's primary structure was analyzed and static tested in 1999 to factors lower than typically used by NASA today. Safety factors and proof factors were less than specified by NASA-STD-5001.

NESC Contribution: The NESC performed an independent review for the Phoenix Project structural analysis processes. Recommendations were made, including reassessing margins against more current loads, which the Project accepted, to ensure structural integrity for all phases of the mission.

Paul Mirabal, of the WSTF Hypervelocity Test Team, prepares a projectile representative of a micrometeorite or orbital debris that will be accelerated to approximately 7 km/s and impacted on candidate CEV composite crew module materials.



NESC Supporting the Constellation Program

The NESC has been increasingly involved in supporting the Constellation Program's Crew Exploration Vehicle (CEV) and Crew Launch Vehicle (CLV) Projects. This past January, a CEV Smart Buyer Team was formed at the request of the Constellation Program Manager to identify major design drivers and develop innovative design concepts for the CEV. The NESC organizational structure was used to bring together over 200 members with representation from each of NASA's 10 Centers, Headquarters and industry. This intense 8-week effort not only produced a detailed design, but also demonstrated that NASA has the in-house capability to perform a multi-Center, integrated design. The NESC is now engaged in numerous assessments that have grown out of the Smart Buyer activity.

LaRC

NESC Director Ralph Roe, Jr. leads a panel discussion during the Smart Buyer kick-off meeting. Seated from left, Dr. Michael Griffin (NASA Administrator), Dr. Scott Horowitz (Associate Administrator for Exploration Systems), William Gerstenmaier (Associate Administrator for Space Operations), Doug Cooke (Deputy Associate Administrator for Exploration Systems) and Jeffrey Hanley (Constellation Program Manager).

Crew Exploration Vehicle Launch Abort System Aero Evaluation

Problem: The Associate Administrator for the Exploration Systems Mission Directorate requested that the NESC examine the aerodynamic drag sensitivity to the launch abort tower geometry parameters (length, diameter, nose bluntness) for both the Launch Abort System (LAS) and the Crew Launch Vehicle (CLV) with an alternate side mounted Service Module abort motor (referred to as the LAS-2B) configuration.

NESC Contribution: The NESC conducted a study using a combination of Computational Fluid Dynamics (CFD) analyses and wind tunnel testing. The results of the CFD study on the LAS tower geometry indicated that the primary geometric parameters affecting drag are the nose tip shape and the tower diameter. The LAS tower length was only a secondary parameter in the overall drag sensitivity, and a short tower design can be as effective as a longer tower to reduce the total drag. The results of the wind tunnel test indicated that the transonic and low supersonic drag associated with the Alternate LAS-2B strap-on motors was significantly higher than the baseline LAS tower configuration, and resulted in reduced payload-to -orbit capability of the CLV.

MSFC

At right, Schlieren photos of CEV wind tunnel models of the Baseline Tower LAS (top) and the alternate Side Mount LAS (bottom).

Crew Exploration Vehicle Composite Crew Module Feasibility Study

Problem: While the Agency has significant experience with composite design and fabrication, there is a need to increase expertise in habitable composite spacecraft. Following the CEV Smart Buyer effort, the NESC took on the task of developing a composite CEV crew module as a means to assess the viability, of a composite design, while allowing the Agency to build on its composite structure expertise.

NESC Contribution: The spacecraft community had identified potential technical design drivers in the use of composite materials for the primary structure of the crew module and the NESC team evaluated the challenges and identified solutions or strategies for managing those technical challenges. The design drivers including mass, geometry, manufacturability, inspectability, repairability, damage tolerance, crashworthiness, and radiation shielding.

Three different composite concepts were identified: a geometrically stiffened laminate, a stiffened honeycomb sandwich, and a monocoque that integrates the aeroshell and pressure vessel into one thick layup. All three concepts had design, analysis, and sizing iterations and all three concepts were evaluated for the design drivers described before. The NESC concluded that preliminary composite solutions are technically competitive with the metallic solutions but the team did not quantify a significant discriminator driving toward a composite solution for the CEV crew module.

Geometrically stiffened laminate

Stiffened honeycomb sandwich.

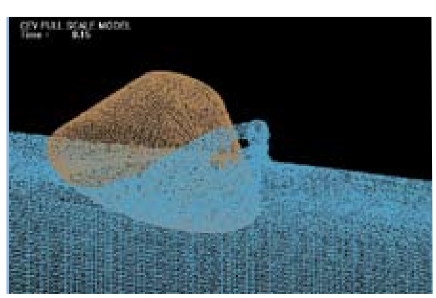
Monocoque that integrates the aeroshell and pressure vessel.

Crew Exploration Vehicle Crew Module Water Versus Land Landing Assessment

Problem: The Systems Engineering & Integration Office within the Constellation Program requested that the NESC independently evaluate the risk and life cycle cost of landing the Crew Exploration Vehicle (CEV) on water versus land.

NESC Contribution: The NESC team based the analysis on the current CEV design, augmented by historical Apollo Command Module (CM) operational water landing and land impact testing. Quantitative risk analyses were performed for water and land landing vehicles. Potential system faults that could result in a contingency land impact were evaluated for the early phases of liftoff, including pad-abort, as well as the return entry, descent and landing phases. Life cycle costs of the two landing configurations were developed along with estimated recovery costs for both land and water recoveries. Landing risks to the crew were analyzed using landing simulations of CEV models and analysis of Apollo water and land impact test data. Analysis revealed that the relative risk to the crew is substantially lower by one or two orders of magnitude for a water-only vehicle design. Further, a contingency land landing in a water-only design increases risk to the crew.

This latter conclusion was developed from analysis of the Apollo land impact tests. Apollo land impact accelerations, measured within the bodies of crash test dummies, were subjected to modern analyses techniques and revealed that the crew would likely sustain injury for most land impacts. Apollo impact data also revealed that simulated hypergolic fluids stored below the pressure vessel entered the crew cabin after some impacts. The NESC advised the Program to flight test a water landing capability prior to the nominal water landing capability and recommended several design features for the CEV Earth Landing System to mitigate risks to both the crew and vehicle while maximizing reusability. At termination of the Apollo Program, each subsystem lead engineer developed an engineering document which chronicled the design, development and testing of their subsystem. This data was invaluable when developing the CEV design.



Renderings/GRC

LS-Dyna® simulation of a CEV water landing.

Lessons Learned: Detailed engineering descriptions of legacy systems and engineering decisions are invaluable when designing new systems and should be developed or compiled and formally archived at the end of a program.

Crew Launch Vehicle Roll Torque Evaluation

Problem: The Crew Launch Vehicle (CLV) is an aerodynamically unstable configuration with a center of pressure significantly forward of the center of gravity. Consequently, the pitch and yaw control provided by the first stage solid rocket motor nozzle will be critical for trajectory control. The CLV Reaction Control System (RCS), located near the aft end of the upper stage, will be the sole reaction method to all torque inducing forces acting upon the CLV during flight. The CLV Project requested that the NESC examine the known contributors to roll torque and assess if the current RCS concept provides sufficient margin to account for all design requirements. The CLV Project also solicited an independent assessment of methods for characterizing the magnitude of roll torque contributions from a full-scale horizontal static firing of the first stage motor.

Photos/ATK Thiokol

Test firing of a Space Shuttle Solid Rocket Motor at ATK Thiokol in Promontory, Utah. T-97 test stand will be instrumented for roll torque measurements.

NESC Contribution: The NESC did not identify any additional roll torque contributors beyond first and second stage systems tunnel, the first stage nozzle centerline offset, and solid propellant combustion products rotational flow. Examination of the thrust and propellant weight sizing analysis and associated assumptions and boundary conditions indicates the proposed RCS is adequately positioned and proportioned to counter predicted roll torque contributions. The NESC also provided specialized technical expertise in areas of Design of Experiments (DOE) and Response Surface Methodology in recommended changes to the test plan for attempted roll torque measurements during a full scale horizontal firing of the first stage motor.

Lessons Learned: Complex load measurement devices should be calibrated as a system with external inputs applied to sufficiently characterize the force response uncertainties. Failure to recognize the system load measuring attributes can result in error band uncertainties greater than the force measurements themselves.

Crew Launch Vehicle Ares Preliminary Design Assessment

Problem: The Crew Launch Vehicle (CLV) pursued a risk mitigation approach to potentially unrecognized structural or control issues by soliciting an independent evaluation of the vehicle design by the NESC. The NESC was requested to identify barriers to vehicle design that require resolution prior to the investment of detailed analysis resources.

NESC Contribution: The NESC effort identified structural and guidance, navigation and control design guidelines from historical and discipline reference information and other applicable design experience. These design principles were evaluated against the Exploration Systems Architecture Study (ESAS) base configuration, primarily at the maximum aerodynamic pressure conditions, in an effort to identify any design barriers. This design configuration was evaluated

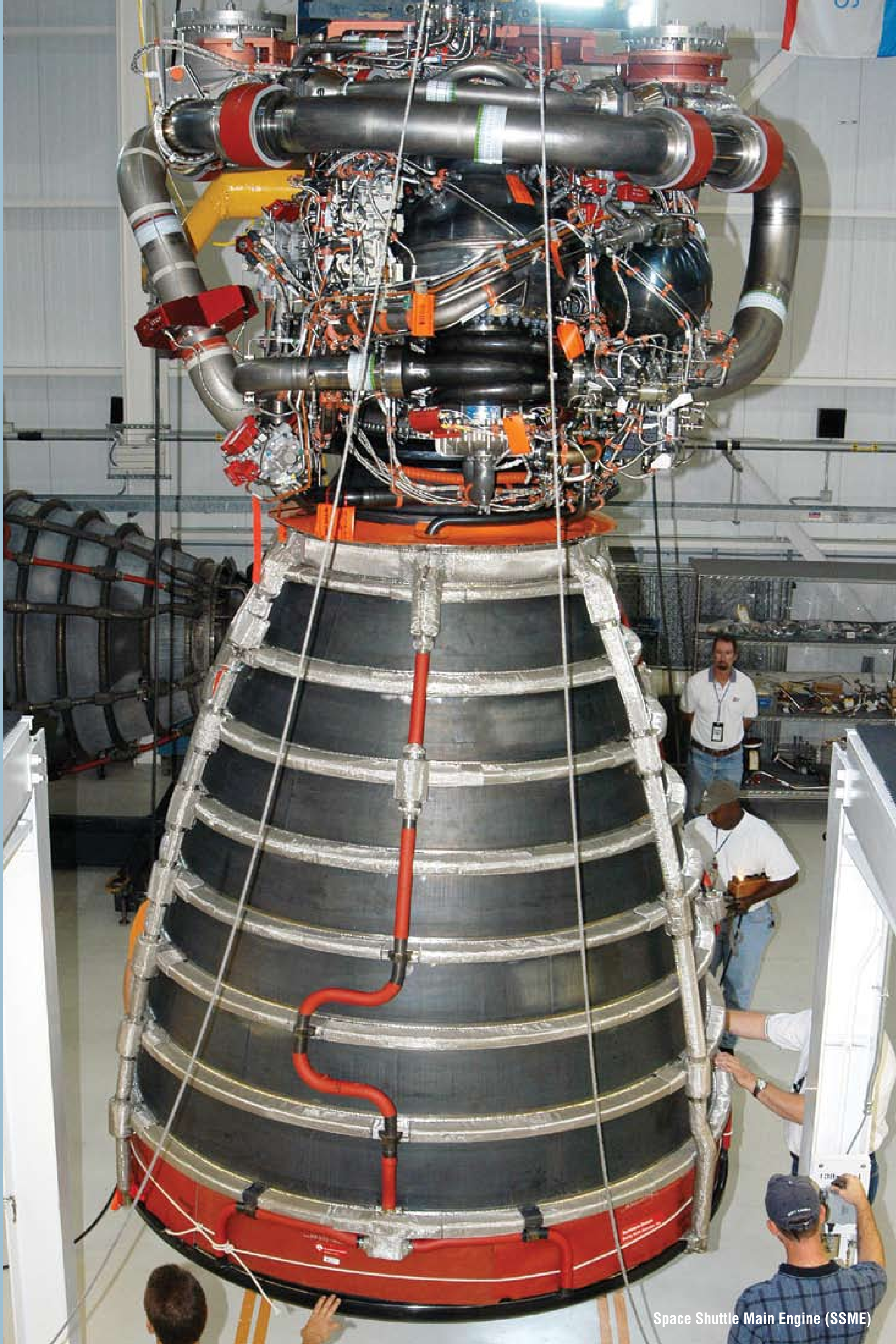
MSFC

Schlieren photograph of supersonic flow around a model of the CLV. The NESC analyzed aerodynamic data as part of the assessment.

because models of the proposed five-segment solid propellant first stage/J-2X liquid propellant upper stage concept were not available and any issues identified would probably be a concern for any concept with a greater total vehicle height. The assessment did not reveal any "physical barriers" at the current maturity of the CLV design that would prohibit structural or control viability. However, a number of design watch topics were identified that include several vehicle control and first stage structural limits that require detailed investigation to determine their criticality.

Lessons Learned: Proactive requests seeking independent technical review during the preliminary concept phases are invaluable risk mitigation initiatives at identifying critical design limitations. The recognition of configuration issues at the earliest opportunity in the design development vastly improves the likelihood of meeting mission objectives.

featured technical paper



Space Shuttle Main Engine (SSME)

Fracture Mechanics Analysis of LH2 Feed Line Flow Liners

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Inspections of the Space Shuttle Main Engine revealed fatigue cracks growing from slots in the flow liner of the liquid hydrogen (LH2) feed lines. During flight, the flow liners experience complex loading induced by flow of LH2 and the resonance characteristics of the structure. The flow liners are made of Inconel 718 and had previously not been considered a fracture critical component. However, fatigue failure of a flow liner could have catastrophic effect on the Shuttle engines.

A fracture mechanics study was performed to determine if a damage tolerance approach to life management was possible and to determine the sensitivity to the load spectra, material properties, and crack size. The load spectra were derived separately from ground tests and material properties were obtained from coupon tests. The stress-intensity factors for the fatigue cracks were determined from a shell-dynamics approach that simulated the dominant resonant frequencies. Life predictions were obtained using the NASGRO life prediction code. The results indicated that adequate life could not be demonstrated for initial crack lengths of the size that could be detected by traditional NDE techniques.

I. Introduction

DURING an inspection of the Space Shuttle Main Engine, fatigue cracks were found in the flow liner of the liquid hydrogen feed line. The flow liner was designed as a non-structural member that is used to maintain laminar flow of the fuel in the feed line and has not been considered to be fracture critical. Because the flow liner is not a structural member, it became apparent that the loading that initiated and propagated the fatigue cracks was induced by the complex flow physics of the liquid hydrogen interacting with the resonant characteristics of the flow liner. As a result, the analysis of the crack growth behavior required a multi-disciplinary approach that derived input from a variety of sources, including flow physics, dynamics, existing and new experimental results, destructive and non-destructive evaluation results, and existing and new fracture mechanics analyses. Detailed investigations and laboratory testing indicated that the vibration could be characterized by several dominant resonant frequencies, one during each of the various major stages of launch and flight into orbit [1].

This paper describes a fracture mechanics-based evaluation that was undertaken to determine if a damage tolerance approach to life management was possible and to determine sensitivity to loads, material properties, and crack size. The approach used was to develop a fracture mechanics-based stress-intensity solution for the various crack growth scenarios. Then, the loading derived in cooperation with the flow physics and dynamics teams was applied. Life predictions were made using the fracture mechanics software NASGRO [2]. Several initial crack sizes were considered, and for each of these crack sizes, the life prediction calculations were performed. Several ranges of the magnitude of welding residual stresses, material crack growth rate characteristics, and other salient variables

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This paper was presented at the 47th AIAA Structures Dynamics and Materials conference in Newport, Rhode Island, May 1-4, 2006

were also considered. For each of these combinations, the life prediction calculations were performed to provide insight into flight safety, inspection intervals, and inspection criteria.

II. Flow Liner Configurations

The upstream liner is a cylindrical shell and the downstream liner is a doubly curved cylindrical shell; both are about 12 inches in diameter and about 3 inches wide by about 0.05 inches thick, (see Figure 1). The liners are each welded at opposite ends (as indicated by the green hash marks of Figure 1) of the main structure at a joint in the feed line, and the liners overlap in the middle to maintain the laminar flow through the joint. Each flow liner has slots oriented in the direction of the flow. Fatigue cracks initiated and propagated from the slots both axially at locations A and D and circumferentially at locations B and C in Figure 2.

Cracks that initiate at locations A and D have been shown to be self limiting [1]. At location A, the crack is growing from the thin sheet liner into the thick structure that is near the weld, and thus the driving force is reduced. However, the residual stresses are highest at this location because of its proximity to the weld. For location D, detailed shell finite element analyses showed that crack growth away from a slot towards the edge of the liner initially increases, but then decreases because the structure resonance changes with crack growth. The two circumferential locations, locations B and C, have approximately the same stresses, but location B has a higher residual stress because it is closer to the weld. The current investigation selected location B for detailed examination because the residual stresses make location B more critical than location C, and the crack growth does not appear to be self limiting like at locations A and D.

Failure of a circumferential crack in a liner occurs when the crack has grown across the entire ligament (a length of 0.75 in.). A completely cracked ligament can form a tab that can break off and get ingested into the engine. Such an ingestion can cause catastrophic damage to the engine and the Shuttle. The current analysis defines failure when the circumferential crack grows to a length of 0.6 in. This is a slightly more conservative assumption than the crack growth across the complete ligament length of 0.75 in. (The difference in lives for a crack length of 0.6 in. in comparison to 0.75 in. is shown to be negligible [1].)

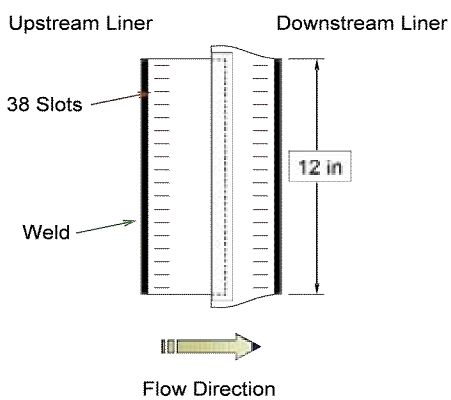


Figure 1. Upstream and downstream flow liners.

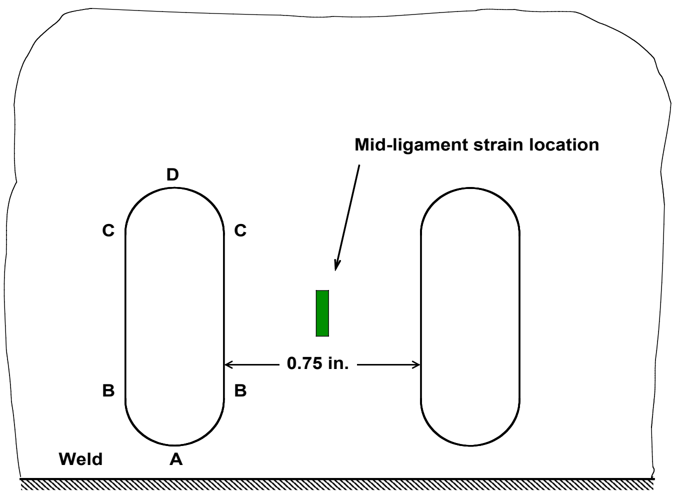


Figure 2. Schematic of cracking locations around a typical slot and locations of strain measurement.

III. Loading

The flow liners are subjected to complex loading due to the resonant response to the liquid hydrogen flow field. The computational fluid dynamics (CFD) and the flow-physics teams investigated large scale unsteady motions of the mean flow, back flow, and changes in the acoustic modes. The loads and the dynamics team, utilizing flow tests performed at Stennis Space Center [1] intended to simulate flight conditions, as well as flow-physics/CFD results, identified a predominant 3500 Hz complex 9ND mode (complex here refers to both membrane and bending modes acting simultaneously) for the upstream liner and 3ND (1650 Hz), C4ND (3300 Hz), and 5ND (1070 Hz) modes for the downstream liners. (*j*ND here refers to the *j*-nodal diameter mode shape, and C denotes complex mode shape.)

Based on the test data and analytical results, fatigue-loading spectra were developed [1] to simulate the loads experienced during engine operation in one flight. (In one flight the engines run for about 500 seconds). These spectra are used in the current fracture mechanics analyses.

The loading spectra are based on strains measured in the flow liner test article at the mid ligament locations between the slots (see Figure 2) during tests performed at Stennis Space Center [1]. These strains are used as scale factors on the loading spectra to evaluate the stress-intensity factors. A high level of uncertainty exists in the magnitude and sequence of the flight spectra due to the complexity of the flow field and reliance on ground simulations. The details of this approach were described in Reference 1.

IV. Life Prediction Modeling

The life prediction code NASGRO Version 4.11 [2] is used for all crack growth predictions. The stress-intensity factors are entered using a 1-D data table (DT01) option. The user dimension, D, is 0.75 in. (the width between the slots). The loading spectra are entered as separate load cases for mean bending, alternating bending, and alternating membrane. The load cases are superimposed in NASGRO during the life calculations. All life calculations are performed using the NASGRO non-interaction model to ensure the most conservative life calculations. The non-interaction model performs linear accumulated damage crack growth and deactivates plasticity induced retardation models.

Load ratio (R) effects, such as plasticity or roughness-induced crack closure, are extrinsic effects that decrease the crack growth rate by reducing the amount of damage caused by the cyclic loading and thus extend life. These effects are strongly dependent on the order and magnitude of loads in the flight spectra. The inclusion of crack closure into a life prediction analysis will produce less conservative results and cannot be justified when the uncertainty of load spectra is high. The loading used in this analysis had a high level of uncertainty, thus the load ratio effects were excluded from the life analysis.

For positive load ratios, the crack growth rate relationship is described by a modified form of the NASGRO equation that results from enabling the load ratio bypass option:

$$\frac{da}{dN} = \frac{C\Delta K^n \left(1 - \frac{\Delta K_{th}}{\Delta K}\right)^p}{\left(1 - \frac{K_{\max}}{K_c}\right)^q} \qquad (R \geq 0) \tag{1}$$

Where ΔK is the stress-intensity factor range, $K_{\max}$ is the maximum stress-intensity factor, K_c is the fracture toughness, ΔK_{th} is the threshold stress-intensity factor range, and C, n, p, and q are curve fit (Paris-like) parameters [2]. In Eq. (1), the entire ΔK range contributes to crack growth. The ΔK_{th} term is still a function of R and allows Eq. (1) to fit the high R data near threshold.

For negative load ratios, the NASGRO equation reduces to:

$$\frac{da}{dN} = \frac{C\Delta K_{\max}^n \left(1 - \frac{\Delta K_{th}}{\Delta K}\right)^p}{\left(1 - \frac{K_{\max}}{K_c}\right)^q} \qquad (R < 0) \tag{2}$$

Thus, for negative load ratios, only the tensile part of the load cycle is active and the crack is assumed to be closed during the compressive part of the load cycle. The loading of the flow liners is predominantly high mean stress loading with an alternating component that is smaller than the mean stress. Thus, Eq. (2) will have an insignificant influence on the NASGRO life predictions for the flow liner loading spectra.

V. Material and Material Model

The flow liners are constructed using Inconel 718 and operate at a temperature of -423° F. The material data used for the analyses was generated using liquid helium (LHe @ -423° F) by researchers and engineers at NASA Marshall Space Flight Center. The liquid helium test was performed using a temperature controlled spray technique that allowed simulation of a liquid hydrogen temperature using the inert helium. Tests were performed to characterize the closure free (at or above high load ratios of R= 0.7) intrinsic fatigue crack growth response over a wide range of rates from threshold to fracture. Tests were also performed to characterize the low load ratio (R=0.1) in the Paris regime to establish the effect of plasticity induced closure; however, as mentioned above, only the high load ratio results were used in the life calculations.

The loading for the orbiter flow liner is approximated by spectra developed from flow tests intended to simulate flight conditions; however, a high level of uncertainty exists for the actual loading. The fracture mechanics-based life predictions rely on accurate loads, and in particular, an accurate description of the load ratio R (the ratio of minimum to maximum load). High load ratio crack growth rate data describes intrinsic material behavior. Low load ratio crack growth rate data describes material behavior that is affected by extrinsic effects such as plasticity induced crack closure. These extrinsic effects can have a significant influence on crack growth rate, thus on the life predictions as well. For example, R = 0.1 data commonly has crack growth rates that are a factor of 5 lower than R = 0.9 data at the same value of ΔK. The inclusion of load ratio effects could increase the calculated fatigue life (making predictions less conservative) in a manner that cannot be supported due to uncertainties in the assumed loading. Thus, the crack growth rate behavior for all load ratios is forced to coincide with the R = 0.9 crack growth rate curve approaching threshold.

Figure 3 is a schematic of the material model for the crack growth rate data. The two NASGRO parameters, $S_{max}/Flow = 1$ and $Alpha = 5.845$, are used to minimize the load ratio effect. This is referred to as the *NASGRO load ratio bypass* option. Three additional NASGRO parameters, *p, DK1,* and C_{th}, control the fit to the high load ratio data in the threshold regime. The curves shown in Figure 3 exhibit no load ratio effect at threshold. In addition, the *'C_{th} value option'* was set to *'mat'l file value throughout'* to enforce that the fit to the high load ratio data was consistent throughout the analysis. The K_{max} (near-fracture) behavior was allowed to maintain the load ratio influences, as indicated by the separation of the curves at large ΔK values, as in Figure 3.

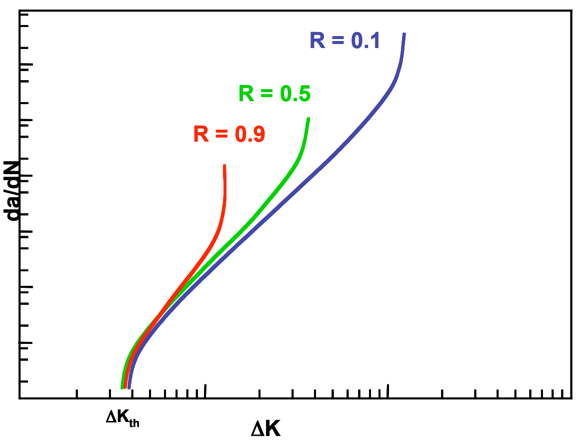


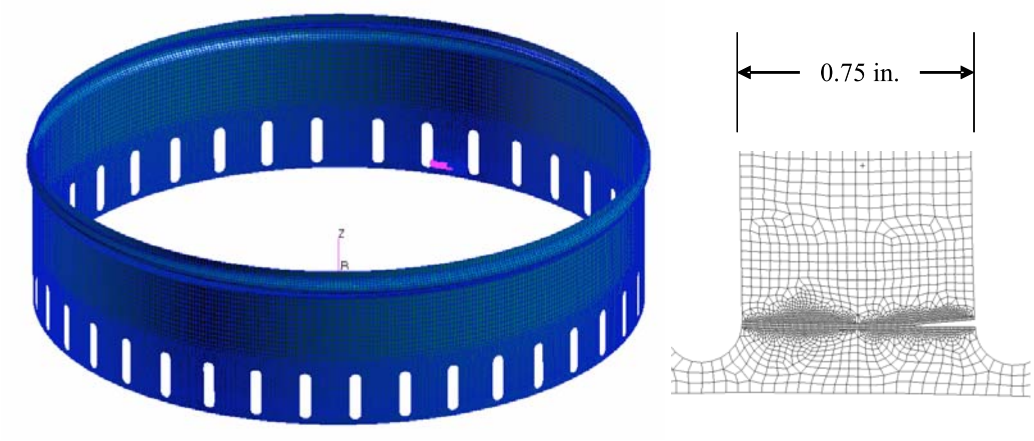
Figure 3. Notational material model for the crack growth rate data.

VI. Threshold and Crack Size Considerations

Experimental evidence from ground test articles indicate that the flow liner cracks initiate as corner cracks from surface defects that are of the size of the material microstructural features (e.g., grain size). Linear elastic fracture mechanics (LEFM) may not be applicable for cracks that are small relative to the material microstructure. Two fundamental limitations for small crack modeling are: (1) microstructurally and mechanically small cracks cannot be represented by simple continuum LEFM crack models, and (2) microstructurally small cracks may have different threshold behavior than the long crack material data available for the material models. To overcome the first of these limitations, the crack size must be large enough that the crack can be approximated as a continuum crack. A continuum crack has a cyclic plastic zone that is small compared to the length of the crack, but large relative to the size of the microstructural features. A crack that has a length greater than 10 grain sizes can generally be considered a continuum crack. Inconel 718 has reported grain sizes of 5 – 40 μm (0.0002 – 0.0015 in.) [1]. This grain size would require that a crack be 50 – 400 μm (0.002 – 0.015 in.) long to be considered a continuum crack. Therefore, the analyses consider cracks larger than 0.02 in. to maintain LEFM applicability.

VII. Approach for Stress-Intensity Factors

A shell dynamics-based approach is used in the evaluation of stress-intensity factors. In this approach, a modal dynamic analysis of an uncracked shell model of a flow liner is performed. The representative mode of excitation in the shell is identified, a crack is introduced into the model, and the strain energy release rates at the crack tip are calculated using the eigenvector of the corresponding shell mode. The stress-intensity factors are then evaluated from the strain energy release rates using the deformed mode shapes that the liner experiences.



(a) Typical full liner model. (b) Typical refined mesh near the crack.

Figure 4. Typical shell finite element model.

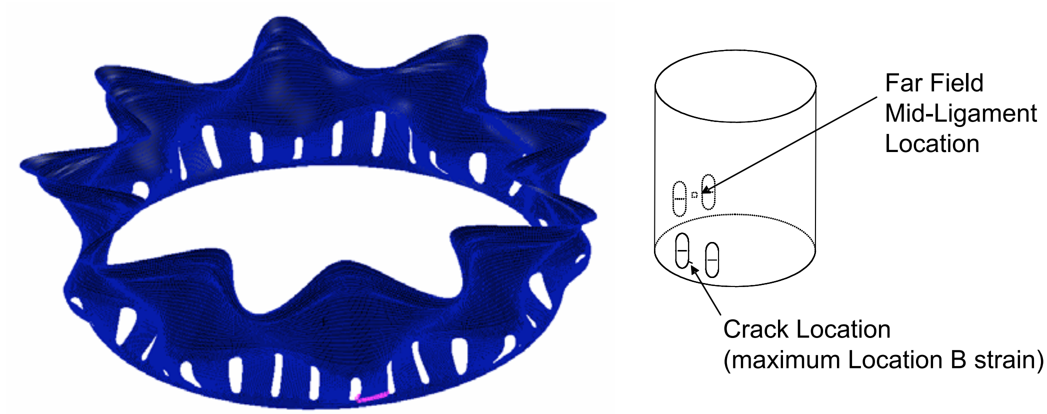


Figure 5. Far-field ligament for scaling the eigen-value results.

A typical shell finite element model of the upstream liner is shown in Figure 4. Using this model, a modal analysis is performed to isolate the dominant mode shapes (i.e. C9ND for the upstream liner). The deformed shape of the upstream liner, based on the eigenvector corresponding to this mode shape, is shown in Figure 5. Typical values of the normalized axial stress at the mid-ligament locations are plotted in Figure 6 for all of the ligaments an uncracked flow liner. As expected, the distribution shows a certain amount of cyclic symmetry for the C9ND mode shape. Similarly, the axial stresses at location B in all the slots are examined and the slot with the highest stress at location B is isolated. (There may be more than one slot with the same peak stress. In such a case, any one of those slots is chosen). The slot with the highest axial stress at location B is at φ = 340°. A circumferential crack is introduced at this slot, as shown schematically in Figure 7, and a

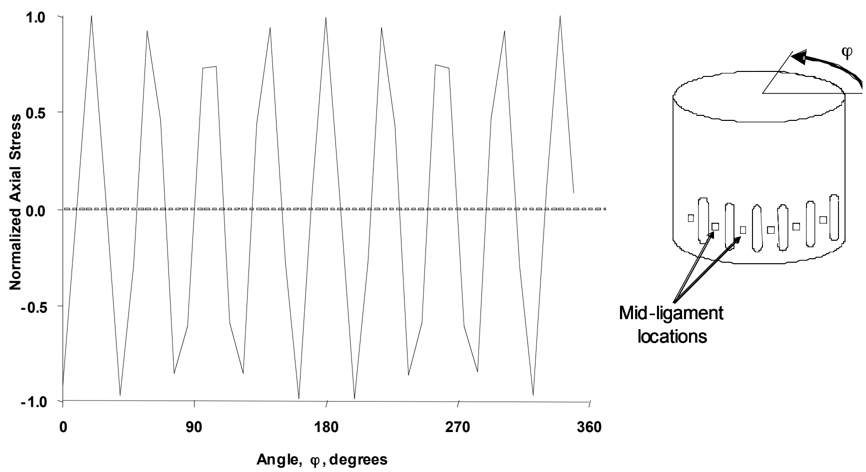


Figure 6. Typical normalized axial mid-ligament stress for the C9ND mode shape.

new shell finite element model with the crack is developed and re-analyzed.

The mode shape corresponding to the C9ND mode is isolated for the new model with the crack. The quantifiable values of the liner deformations are obtained by scaling the eigenvector with the strain gage data collected in previous ground flow liner tests [1]. The scaling process matches the maximum mid-ligament strain to strain gage measurements made at the same location. The C9ND analysis found three mid-ligament locations with nearly the same peak value, so the scaling is based on the one that is farthest (φ = 180°) from the slot with the crack. This location is used to scale all deformations and forces for each crack length analyzed. The process is repeated for the downstream liner.

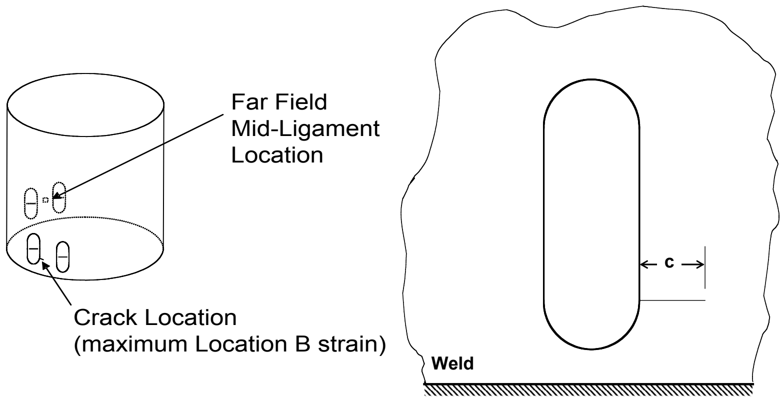


Figure 7. Schematic showing the circumferential crack at the slot with the highest location B stress.

VIII. Stress-Intensity Factors

The stress-intensity factors are calculated from the strain energy release rates using virtual crack closure techniques, as shown in Figure 8 [5, 6]. F_x, F_y, and F_z are the respective forces at the crack-tip node in the x-, y-, and z-directions; M_x, M_y, and M_z are the respective moments about the x-, y-, and z-directions; u_x, u_y, and u_z are the respective displacements at a node behind the crack-tip along the x-, y-, and z-directions; and θ_x, θ_y, and θ_z are the respective rotations at a node behind the crack about the x-, y-, and z-directions. t is the thickness of the shell and Δc is the length of the element behind the crack tip. The finite element models have a fine mesh in the crack region with elements of the same size both behind and ahead of the crack tip (element size Δc = 0.005 in, as shown in Figures 4 and 8).

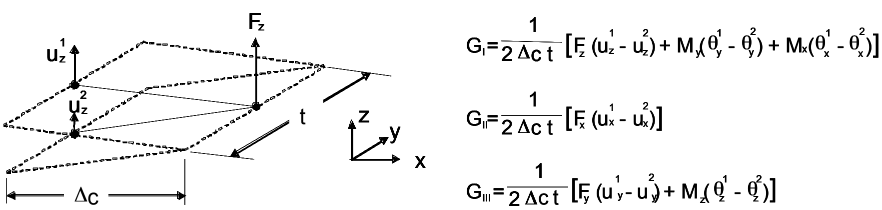


Figure 8. Schematic showing crack tip coordinate system and energy release rate equations [6].

The individual mode stress-intensity factors are calculated from the energy release rates as

$$K_{\mathrm{I}} = \sqrt{EG_{\mathrm{I}}}$$
$$K_{\mathrm{II}} = \sqrt{EG_{\mathrm{II}}} \qquad (3)$$
$$K_{\mathrm{III}} = \sqrt{EG_{\mathrm{III}}}$$

where E is the Young's modulus.

In addition, a total stress-intensity factor is calculated from the total energy release rate.

$$K_{\mathrm{TOTAL}} = \sqrt{E\left(G_{\mathrm{I}} + G_{\mathrm{II}} + G_{\mathrm{III}}\right)} \qquad (4)$$

Figure 9 presents stress-intensity factor as a function of crack length calculated for the single active mode (C9ND) in the upstream liner. For each crack length, the C9ND mode shape is isolated and the stress-intensity factors are calculated from the energy release rates. The values presented in this figure are scaled to a unit value of far-field mid-ligament stress. Mode I is nearly constant and is dominant for crack lengths less than 0.3 in. (where most of the fatigue life is accumulated). The Mode III contributions increase with increasing crack length with the Mode III about equal to the Mode I component for crack lengths greater than 0.4 in. The Mode II component is insignificant.

The largest crack length considered in the shell-dynamic analysis for this comparison and for the life predictions is 0.6 in. because longer crack lengths exhibit a considerable Mode III component of the stress-intensity factor. The material data used to characterize crack growth behavior was derived from Mode I crack growth rate tests and is not necessarily appropriate for Mode III dominated crack growth. Most of the life is consumed while the crack is a corner crack (or short through-the-thickness crack), so stopping the life prediction at 0.6 in. is conservative and makes little difference to the overall calculated life.

The analysis presented above for the upstream liner is repeated for the downstream liner. Recall that in the downstream liner there are three modes, 3ND, C4ND, and 5ND, that are active. The stress-intensity factors are calculated for various crack lengths using the shell-dynamics approach for the three modes and are presented in Figures 10 - 12.

The stress-intensity factors for the four modes considered show wide ranging behavior in Figures 9 - 12. In all cases, when the crack is small (compared to the ligament), the stress-intensity factor is dominated by the Mode I value. However, as crack growth and load redistribution occur, each of the four modes responds differently. In all of the cases, the Mode I stress-intensity factor continues to contribute to a varying degree. The C9ND shape leads to near equal contributions of Modes I and III that monotonically increase, with an insignificant Mode II. In contrast, the total stress-intensity factor for the C4ND shape decreases after a peak value that occurs at about 0.1 in. of growth. These results indicate that modal deformations can lead to complex fracture mechanics behavior.

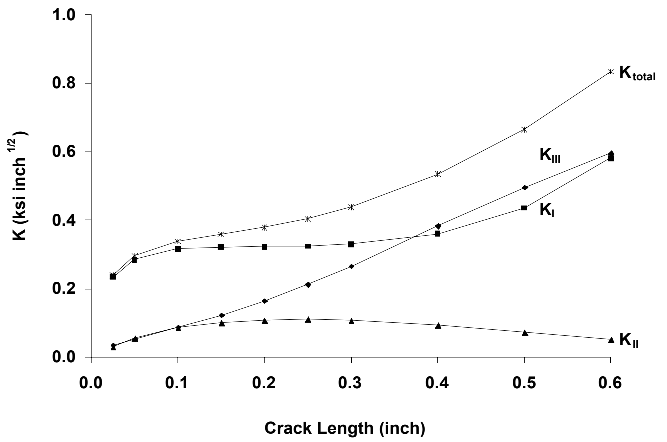


Figure 9. Stress-intensity factors for the shell-dynamics model for the C9ND mode – upstream liner.

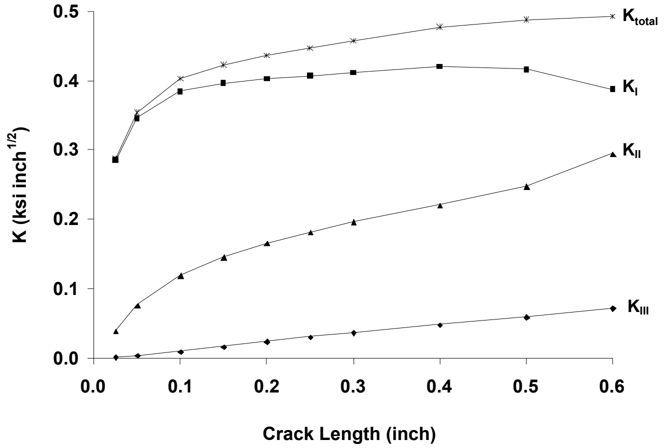


Figure 10. Stress-intensity factors for the shell-dynamics model for the 3ND mode – downstream liner.

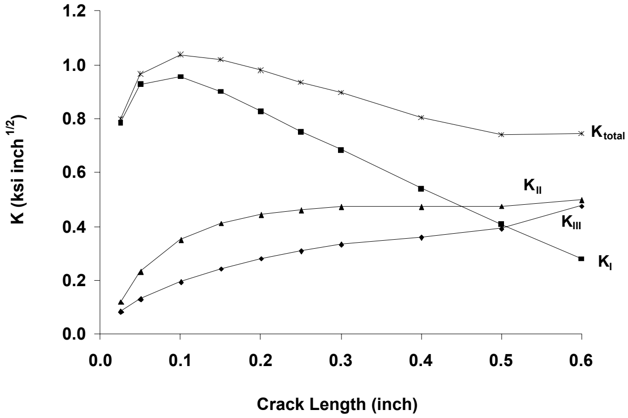


Figure 11. Stress-intensity factors for the shell-dynamics model for the C4ND mode – downstream liner.

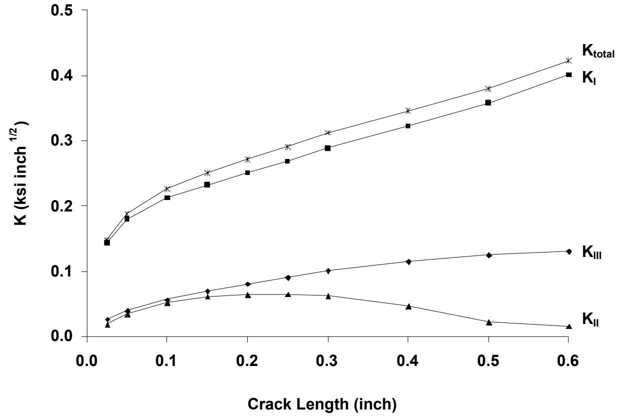


Figure 12. Stress-intensity factors for the shell-dynamics model for the 5ND mode – downstream liner.

IX. Results

The shell-dynamics K_{TOTAL} stress-intensity factors are used in the NASGRO calculations. The loading spectra are calculated as mid-ligament stresses and are used to scale the modal stress-intensity factor results. These new results are then used to calculate fatigue lives for both liners at location B, as summarized in Table 1. An alternate procedure, termed the "transfer factor (TF) approach", is used to evaluate the life of the liners in Reference 1, and the results are included in this table for comparison. The transfer factor approach is very conservative and predicts lives of less than one flight.

As seen from this table, the shell-dynamic approach predicts longer life for the upstream liner compared to when the TF approach is used. The predicted fatigue life for the downstream liner is also longer using the shell-dynamics approach. However, even with an initial crack length as small as 0.02 in., failure of the downstream liner is predicted in about 1 flight using the shell-dynamics approach. These results suggest that either (or both) the uncertainty in the load spectra leads to overly conservative life predictions or that the structure cannot tolerate cracks that can be found with traditional detection techniques. The flow liner cracking problem can be mitigated using any of the three following approaches:

Table 1. Predicted lives for upstream and downstream liners.
(Crack assumed at location B, LHe crack growth data at -423° F)

Upstream Liner

Life (flights)

Initial Crack Length, c_i (in)	Shell-Dynamics Approach	TF Approach
0.075	21	0.1
0.02	39	0.3

Downstream Liner

Life (flights)

Initial Crack Length, c_i (in)	Shell Dynamics Approach	TF Approach
0.075	0.2	0.1
0.02	1.0	0.2

1. Refine the load analysis to reduce the uncertainty in the load spectra, allowing the analysis to take advantage of the benefits of load sequence effects.

2. Refine the fatigue crack growth to account for the non-LEFM behavior of small cracks.

3. Develop inspection techniques that allow for the reliable detection of smaller fatigue cracks (<< 0.02 in.) and a process for eliminating the cracks from the structure.

The approach 3 above was chosen and the flow liner fatigue cracking issue was resolved by developing an inspection process that used a high resolution surface replication technique to detect cracks as small as 0.002 in. The process involved replicating a mold of the slot surface and examining the mold with a high magnification scanning electron microscope. The flow liners in the fleet of the three orbiters were examined (684 individual slots) and 50 cracks with lengths of 0.002 in. to 0.05 in. were detected. The texture of the slot surfaces was also examined and locations with the potential to initiate cracks (i.e. scratches and dents) were identified. The cracks and locations with surface damage were polished in an attempt to return the structure to a pristine condition. The flow liners were inspected with the surface replication technique after polishing and again after the Shuttle flight. No new cracks or additional surface damage were detected.

X. Concluding Remarks

A fracture mechanics-based study is performed for cracks detected in the flow liners in Space Shuttle Main Engines. The flow liners experience complex loading induced by complex flow and the resonance characteristics of the liner. A circumferential crack at the edge of the slot near the weld is considered because this location experiences the highest combined stresses. Fatigue loading spectra are developed by the loads and dynamics team, and these spectra are used to evaluate the life of the liners.

A shell-dynamics approach is used to simulate the dominant resonant frequencies experienced by the liner. The modes that correspond to these frequencies are prescribed on the shell, and the slot with the highest stress is identified. A circumferential crack is assumed to exist at the edge of this slot and near the weld. The stress-intensity factor for this crack is evaluated using the dominant mode shapes. The stress-intensity versus crack length for the liner is evaluated. This stress-intensity factor-vs-crack length curve is used with the fatigue spectra to evaluate the life of the flow liners using NASGRO. While the upstream liner shows adequate life, the downstream liner results show that failure will occur within one flight for an initial crack length of 0.075 in.

The flow liner fatigue cracking issue was resolved by developing an inspection process that used a high resolution surface replication technique to detect cracks as small as 0.002 in. The process involved making a mold of the slot surface and examining the mold with a high magnification scanning electron microscope. The detected cracks and locations with surface damage were polished to return the structure to a pristine condition. The flow liners were inspected with the surface replication technique after polishing and again after a Shuttle flight. The flow liners in the orbiter showed no new cracks or additional surface damage.

References

[1] Harris, C. E., et al., "Orbiter LH_2 Feedline Flowliner Cracking Problem," NASA/TM-2005-213787/Version 1.0, NESC-RpP-04-11/04-004-E, July 2005.

[2] NASGRO Version 4.11 Manual, Southwest Research Institute, February 2004.

[3] Metallic Materials Properties Development and Standardization (MMPDS), DOT/FAA/AR-MMPDS-01, Federal Aviation Administration, Office of Aviation Research, Washington D.C., January 2003.

[4] Newman, Jr., J.C. and Raju, I.S., "Stress-intensity Factor Equations for Cracks in Three-Dimensional Finite Bodies Subjected to Tension and Bending Loads," *Computational Methods in Mechanics of Fracture,* S.N. Atluri, Ed., Elsevier, 1986, pp. 311-334.

[5] Rybicki, E.F. and Kanninen, M.F., "A Finite Element Calculation of Stress Intensity Factors by a Modified Crack Closure Integral," *Eng. Fracture Mech*., Vol. 9, pp. 931-938, 1977.

[6] Wang, J.T., Raju, I.S., Davila, G., and Sleight, D., "Computation of Strain Energy Release Rates for Skin-Stiffener Debonds Modeled with Plate Elements," 34th AIAA SDM Conference, La Jolla, California (April 19-21, 1993).

NESC highlights from the centers

Rollback of Discovery to the Vehicle Assembly Building to replace the External Tank.

AMES RESEARCH CENTER

Ames Research Center (ARC) provided expertise to a variety of NESC assessments with high activity in areas of flight sciences, information technology, and human factors.

Flight Sciences

ARC supported the NESC team's independent review of the decision to remove the Protuberance Air Load (PAL) Ramp from the Space Shuttle External Tank by providing essential experience in wind tunnel testing, unsteady aerodynamics, and computational fluid dynamics. ARC also supported the NESC Orbiter tile gap filler activity via thermal protection system expertise through the engineers that help create the original gap fillers. As members of the NESC peer review team for the CEV Aerosciences Project, ARC personnel assessed the computational and experimental plans for developing the aerodynamic and aerothermodynamic databases for the CEV design. ARC also led the NESC-sponsored Stardust entry observations.

ARC

Dr. Franziska Harms of the University of Stuttgart, Germany, and Dr. George Raiche of NASA Ames Research Center install a cooled CCD camera onboard NASA's DC-8 Airborne Laboratory.

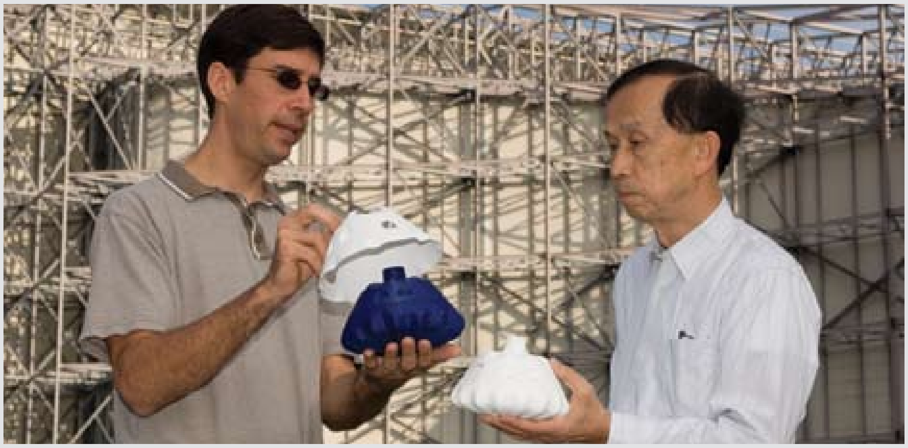
Information Technology

ARC researchers supported NESC efforts in the area of data mining and trending. They developed new algorithms and processes for the Recurring Anomaly Detection System (ReADS), designed to automatically detect recurring anomalies from Problem Reporting and Corrective Action databases. During initial testing, the tool found all but one recurring anomaly previously identified by subject experts and discovered several new ones. These and other results were presented at the Data Mining Applications in Aeronautics and Space Exploration Workshop hosted at ARC. As participants in the NESC-organized CEV Smart Buyer Team, ARC provided expertise in Integrated System Health Management (ISHM) by assessing the relationship of ISHM capability to avionic and software requirements.

Human Factors

The NESC Discipline Expert for Human Factors is resident at ARC. ARC Human Factors experts from the NESC Human Factors TDT were part of several NESC assessment teams including CEV Smart Buyer and the follow-on CEV Water versus Land Landing trade study. Also arranged through the NESC TDT organizational structure, ARC personnel were members of the Genesis and ASTRO-E2 Mishap Investigation Boards uncovering human factor contributions to the accidents. ARC personnel also examined the installation procedures for using Loctite™ on fasteners to improve their reliable use on the ISS.

In addition to the broad discipline areas described above, ARC scientists and engineers were part of several other NESC assessment teams: Reliability for Space Systems, Composite Crew Module, and Field Programmable Gate Array manufacturing standards. Finally, the ARC Supercomputing Facility was used for computer intensive simulations on several NESC assessments.



ARC

Ian Fernandez and Hiro Miura from ARC discuss merits of a geometrically stiffened carbon composite Crew Exploration Vehicle Crew Module design concept. The ARC 80 x 120 ft wind tunnel is in the background.

ARC at a glance

Dr. Dean Kontinos
NESC's Chief Engineer at ARC

■ NESC employees at ARC	2
■ Percent of ARC technical work force who supported NESC assessments	4%

DRYDEN FLIGHT RESEARCH CENTER

Dryden Flight Research Center (DFRC) employees contributed to many NESC multidiscipline teams in addressing the Agency's toughest problems. DRFC acting Chief Engineer, Brad Flick, believes the NESC helps to ensure technical excellence. "The strength of the NESC lies in the network of disciplinary technical experts across the Agency, which can bring their collective knowledge and access to unique tools and test facilities together to solve problems that might otherwise go unsolved. The significant contributions by DFRC's Mike Kehoe and Dr. Kajal Gupta to the [NESC] analysis of the acoustic environment in the SOFIA aircraft is an example of Dryden's participation in efforts that will ultimately lead to the safe and successful accomplishment of a NASA mission."

This year DFRC scientists and engineers supported NESC assessments in the areas of Space Shuttle safety, the Constellation Program, and Nondestructive Evaluation.

NESC Dryden Chief Engineer Dr. James Stewart and Acting Dryden Chief Engineer Brad Flick agree that the NESC plays a key role.

Space Shuttle Safety

Dr. Kajal Gupta was a member of several multi-Center team assessments of issues such as the Space Shuttle Solid Rocket Booster hold-down post stud hang-up, the Space Shuttle's External Tank alternative Ice Frost Ramp design concept assessment, the Space Shuttle wing leading edge impact dynamic analysis assessment and the Space Shuttle Protuberance Air Loads (PAL) Ramp removal feasibility assessment. NESC assessments have allowed Dr. Gupta to collaborate effectively with other national experts in and outside of NASA. His continued activities in the NESC also gave him a broad view of technical problems facing NASA. Other researchers involved have appreciated the One NASA concept in building a consensus on their findings.

Constellation Program

Former Space Shuttle and Apollo astronaut Vance Brand, who serves as Dryden's Deputy Associate Director for Programs, provided his expertise to the NESC in the evaluation of land versus water landings for the Crew Exploration Vehicle, participating as a member of the assessment's Apollo peer review team. In addition, DFRC also provided testing and system engineering expertise to the CEV Smart Buyer Team through participation by Vicki Regenie.

Dr. Kajal Gupta has contributed to several NESC assessments for Space Shuttle safety.

Nondestructive Evaluation

When it comes to embedding fiber optics in composite materials, that's a specialty of Dryden's Dr. Lance Richards, who is providing consultation to an Agency working group responsible for testing Composite Overwrapped Pressure Vessels, or COPVs. As a member of the NESC Nondestructive Evaluation TDT, Dr. Richards is concerned with nondestructive evaluation and structural health monitoring. Richards has consulted with multi-Agency teams regarding sensor installation and measurement interpretation.

Dr. Lance Richards, Senior Research Engineer describes an embedded fiber optic sensor system for composite materials.

DFRC at a glance

Dr. James Stewart
NESC's Chief Engineer at DFRC

- NESC employees at DFRC: **2**
- Percent of DFRC technical work force who supported NESC assessments: **2.8%**

GLENN RESEARCH CENTER

The NESC efforts this year at the Glenn Research Center (GRC) included solid research into Space Shuttle safety, participation in the Smart Buyer activity and exciting new efforts in the Constellation Program.

Space Shuttle Safety

The NESC formed a Bracket Ice Mitigation Team to investigate methods to reduce or eliminate the ice from the brackets that hold the Liquid Oxygen (LOX) feedline to the ET. As a team member, GRC engineers worked on the development of a flexible foam solution that helps prevent ice formation and also allows for the movement of the feedline during tanking, pre-pressurization, launch, and ascent. GRC is responsible for the thermal and mechanical testing and evaluation of candidate materials to eliminate weak performers and to establish guidelines for potential suppliers. Several types of foam were characterized and tested in GRC's full-scale feedline test article that mimics the bracket movements relative to the feedline.

Smart Buyer Participation

Over 40 GRC employees participated on the CEV Smart Buyer Team and hosted the Service Module design activity led by Rick Manella, Engineering & Technical Services Directorate (ETSD), and Derrick Cheston, NESC Chief Engineer at GRC. The team performed four separate design iterations and presented two design recommendations to the Constellation Program and NASA Administrator. GRC personnel led the integration of key disciplines. James Soeder, Advanced Electrical Systems Branch, led electrical power, while Rex Delventhal, Constellation Systems Project Office, led the propulsion element.

Constellation Program

GRC is providing support to the Constellation Program by performing risk analysis in association with the landing strategy for the Crew Exploration Vehicle. GRC has developed vehicle and landing simulations to examine the stresses on the vehicle and accelerations to the crew during landing on water and land. GRC ETSD employees Paul Salano and Chip Redding also led the mechanical system design for the Crew Module

PHOTOS/GRC

NESC Chief Engineer, Derrick Cheston, (far left), NESC Director, Ralph Roe, Jr. (on Cheston's left) and GRC team members participate in Smart Buyer activities from GRC's Integrated Design and Analysis Center (IDAC). The GRC was tied to design centers at GSFC, JSC and MSFC.

Dr. Lynn Capadona in the Orbiter Processing Facility at KSC.

Dr. Charles Lawrence, describes NESC activities underway at GRC.

"...when I joined the Agency, I never imagined in my wildest dreams that I'd be contributing directly to the Shuttle Program at this stage of my career."

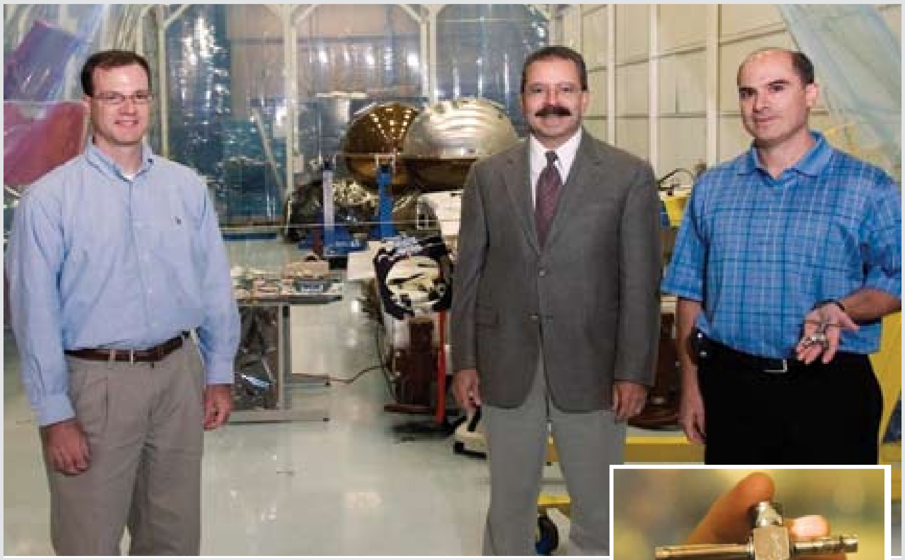
– Dr. Lynn Capadona, member of the Bracket Ice Mitigation Team at GRC

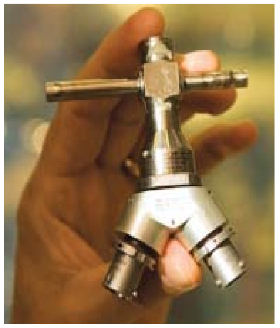
GRC at a glance

Derrick Cheston
NESC's Chief Engineer at GRC

- NESC employees at GRC: **1**
- Percent of GRC technical work force who supported NESC assessments: **8.4 %**

GODDARD SPACE FLIGHT CENTER





PHOTOS/GSFC

Gary Davis, GSFC, SDO Propulsion Lead (far left), requested assistance from the NESC to assess a "non-firing" pyrotechnic valve on the SDO spacecraft (background). Orlando Figueroa, GSFC Director of Engineering (middle), and Michael Hagopian, NESC discuss the pyrotechnic valve (inset).

The Goddard Space Flight Center (GSFC) participated in a wide range of NESC activities, using both NESC personnel resident at GSFC, and matrixed GSFC personnel supporting NESC activities. The NESC Discipline Experts for Guidance, Navigation & Control (GNC), Power and Avionics and Software are resident at GSFC. Over the last year, Goddard personnel have been instrumental participants on many of the NESC teams investigating issues in Space Operations and Science Mission Directorates.

Space Operations

GSFC scientists and engineers focused on the External Tank (ET) liquid oxygen feedline and bracket ice prevention efforts, ET Engine Cut-off sensor performance, Orbiter Rudder/Speed Brake and Body Flap Actuator lubrication, and tin whiskers in Orbiter avionics boxes. GSFC also supported NESC teams investigating issues for the ISS, including: the Control Moment Gyro-1 failure, Corona effect on an S-band RF electronics box, fiber optic workmanship, Station-to-Orbiter Power Transfer Unit reliability, the safety of the Orbital Repair Maneuver, and the ISS camera shutdown anomaly. GSFC also served as the focal point for the Agency-wide Smart Buyer activity.

Science Missions

The technical aspects of some GSFC programs have also been the subject of NESC review. GSFC Center-level management requested an independent review of the flight adequacy of the GOES-N Composite Overwrapped Pressure Vessels (COPV's) installed in the Delta IV 1st and 2nd stages. The GSFC Engineering Director later asked for an independent assessment of the current health and adequacy of processing plans for the GOES-N battery prior to launch. This support helped resolve a difference of opinion between GOES management and the in-line engineers.

Goddard engineering also asked the NESC to independently review ST-5 separation dynamics analyses in support of the ST-5 launch. Recently the Solar Dynamics Observatory (SDO) propulsion lead requested the NESC investigate recent failures of the Conax Y-PCA pyrovalve during pyroshock ground testing. Led by the NESC Chief Engineer at GSFC, test and analysis is being performed by a diverse set of experts at multiple NASA Centers and industry.

The NESC has also initiated proactive work in Field Programmable Gate Array reliability and Hitachi Electrically Erasable Programmable Read Only Memory performance, which benefits multiple programs. Goddard personnel also supported NESC activities associated with science missions at other Centers. While program managers and engineers maintain their in-line responsibility for safety, the NESC complements them by providing independent review, using independent funding. GSFC support is critical to allowing the NESC to fulfill its mission

GSFC at a glance

Michael Hagopian
NESC's Chief Engineer at GSFC

- NESC employees at GSFC **4**
- Percent of GSFC technical work force who supported NESC assessments **3.4%**

"The NESC continues to fulfill its promise as an Agency-wide technical resource for NASA programs and projects, as well as engineering and safety organizations. Goddard has benefited from the NESC, and its ability to quickly summon strong technical personnel from across the Agency, when we've encountered tough problems on our programs which have required an independent second look. We are also pleased to have supplied some of Goddard's considerable technical expertise to the NESC..."

– Mike Ryschkewitsch/Deputy Director of GSFC

JET PROPULSION LABORATORY

In 2006, JPL participated in numerous NESC studies for the Science, Exploration Systems and Space Operations Mission Directorates.

Science Missions

JPL personnel engaged in independent NESC assessments of the Phoenix Lander mission to Mars to evaluate a factor-of-safety structures issues and also potential issues with “leaky” thruster valves that will be used during descent to the surface of Mars. The Dawn mission to orbit two of the solar systems largest asteroids, required analysis of its large Composite Overwrapped Pressure Vessel (COPV) Xenon propellant tank to determine flightworthiness.

JPL personnel are also contributors in determining the root cause of a recent series of fail-ures in pyrotechnically-operated valves that are used on many NASA spacecraft. JPL is developing methods of visualizing the energetic release of gases and particles within the device using the JPL Pyrolab. The pyro devices are fired into a gelatin-filled cylinder while being photographed using ultra high-speed cameras to aid in detailed analysis. The NESC also contributed to the resolution of a major power outage (high power and high power output application) at the Deep Space Network’s Goldstone facility that is used by all of NASA’s deep space missions.

JPL

The 70-meter antenna at the Goldstone Deep Space Communications Complex

JPL has also been instrumental in the development of design and validation guidelines for next generation Field Programmable Gate Arrays used in many NASA and commercial spacecraft.

Exploration Systems Missions

Using expertise gained from the Mars entry, descent and landing (EDL), JPL engineers and scientists were a part of a Smart Buyer follow-on activity to evaluate landing the Crew Exploration Vehicle (CEV) in water versus land. JPL contributed to quantifying the risk and likelihood of failures in various EDL designs. JPL personnel led the risk analysis for the team that quantified risks to the crew, vehicle and public. JPL personnel are also leading a follow-on study to evaluate the existing NASA and new contractor CEV landing and recovery architectures.

Space Operations Missions

JPL continues to be engaged in the analysis of the long-term safety of COPVs for the Space Shuttle and is also active in data mining and trending of existing problems and failures and issues looking for the trends in data to improve flight safety. JPL has also had three proactive proposals accepted to advance robotic exploration.

JPL

Thomas Rust (left) and Joe Lewis, from the Propulsion and Materials Engineering Section, measure a proof-test version of the COPV used to carry Xenon gas for the ion propulsion system for the Dawn satellite.

JF&A

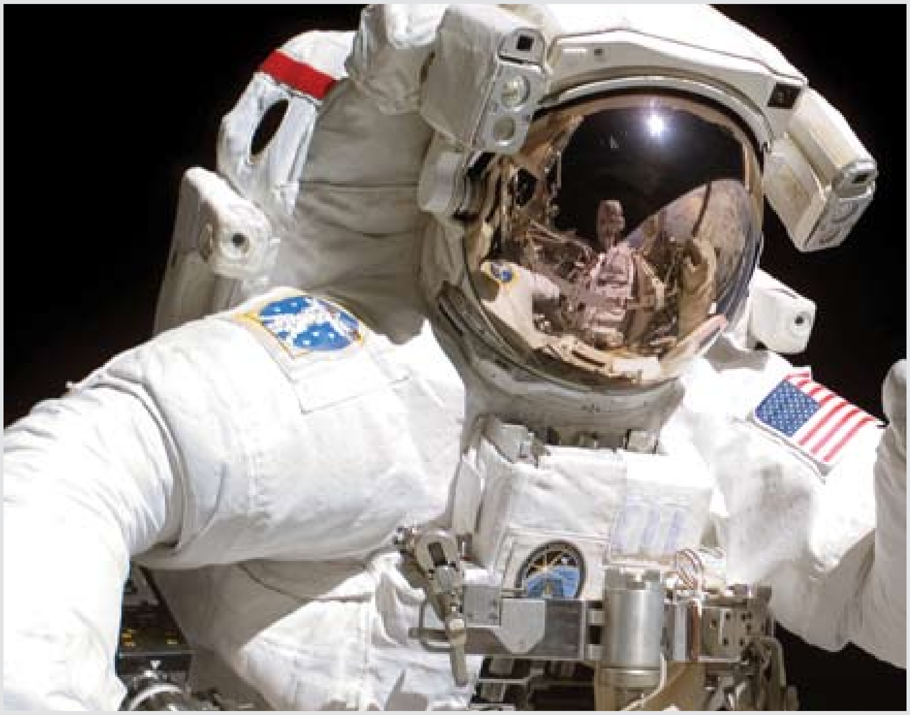
JPL led an NESC study to determine the risks of water versus land landings for the CEV Crew Module.

JPL at a glance

Brian Muirhead
NESC’s Chief Engineer at JPL

- NESC employees at JPL **2**
- Percent of JPL technical work force who supported NESC assessments **5.3%**

JOHNSON SPACE CENTER



JSC

Astronaut Joseph R. Tanner, STS-115 mission specialist, during the first of three spacewalks. Over 60 percent of NESC activities supported the Space Operations Mission Directorate in 2006.

The NESC continued to support the Space Shuttle Program (SSP) and International Space Station (ISS) Program and initiated support to the Constellation Program. Support included technical assessments and independent evaluations, testing, and analyses which utilized expertise from across government, industry and academia. NESC representatives at JSC include the NESC Discipline Experts for Fluids/Life Support/Thermal, Mechanical Systems, Flight Sciences, and Loads and Dynamics. The NESC Chief Astronaut is also resident at JSC.

Return to Flight Activities

The NESC supported the five person Agency-wide ET Tiger Team, which provided senior NASA leadership an independent assessment of the ET foam losses on STS-114. Other issues/tasks supported by the NESC included the thermal protection system repair, reaction jet device redundancy, Composite Overwrapped Pressure Vessel life, ET Protuberance Air Load (PAL) removal effort for STS-121, engine cutoff sensor evaluation, and ISS specific issues including post-proof testing of European modules, control moment gyro failure, trailing umbilical system failure and subsequent launch replacement unit loads/margins, and numerous other tasks supported by the NESC.

NESC representatives kept abreast of Program/Project activities and day-to-day issues with emphasis on Space Shuttle return-to-flight. The NESC provided face-to-face presence with the SSP and ISS Program Managers at the monthly NESC activities status briefings as well as Boards and mission related tagups. The JSC NESC Chief Engineer (NCE) provided periodic status reports to the NCE team on key human spaceflight activities and special briefings on Space Shuttle return-to-flight efforts at each NESC face-to-face meeting. The NESC provided JSC Center organizations senior management with quarterly updated synopses of each NESC Human Spaceflight related NESC tasks and results. The NCE represented the NESC as a member of the SSP Program Requirements Control Board and ISS Program Control Board. NESC representatives provided inputs on Program technical issues based on NESC technical assessments, as well as expert opinions. The NCE represented NESC at all Stage Operations Readiness Reviews for all Soyuz and Progress vehicle launches to the ISS in the critical down period between STS-114 and STS-121.

Constellation Program

NESC TDT members from JSC participated in several studies for the Constellation Program. The Smart Buyer Team activity was supported by a number of experts from JSC. The team was recognized at an awards presentation where the JSC Director presented a group achievement award to each member from JSC.

JSC at a glance

Dave Hamilton
NESC's Chief Engineer at JSC

■ NESC employees at JSC	8
■ Percent of JSC technical work force who supported NESC assessments	2.6%

KSC

The successful launch of STS-121 on the 4th of July, 2006 completed the second of two test flights for SSP RTF activities.

KENNEDY SPACE CENTER

The NESC continues to support Agency and program goals through its efforts at the Kennedy Space Center (KSC). The NESC team was well supported by 45 KSC personnel of various disciplines who were active in NESC assessments and studies this year. Twenty-six NASA personnel at KSC are members of the NESC's Technical Discipline Teams. These discipline expert teams are the primary workforce the NESC calls upon when performing assessments and studies.

The NESC assessed and studied numerous Space Shuttle Program issues this year. Many of those required significant KSC participation. The Cryogenic Test Laboratory (CTL) and Launch Equipment Test Facility (LETF) provided necessary support for several NESC activities. Testing for the Space Shuttle External Tank Intertank Aerogel insulation was performed at the CTL.

Similarly, flammability and water absorption testing for the NESC-funded Shuttle Ice Liberation Coating (SILC) project is in work at several different KSC laboratories. Weather testing for SILC was performed at KSC's beach corrosion facility. KSC Space Shuttle processing facilities and United Space Alliance helped with the Space Shuttle LO2 Bracket Ice study. Foam application for Prototype bracket hardware was sprayed at the Vehicle Assembly Building and machined at the Prototype Lab to simulate ET foam. Potential foam replacements were waterproofed at the Orbiter Processing Facility.

In addition, KSC personnel and capabilities played a key role in numerous other NESC studies. For example: Space Shuttle Crawler/Transporter shoe crack nondestructive evaluation techniques; recurring anomaly studies for Space Shuttle and ISS; Vehicle Assembly Building explosive quantity distance study; data mining techniques; design standard development for systems control in safety critical applications; Space Shuttle tile gap filler consultation; and the Smart Buyer activity are some of the projects sponsored by NESC that depended on KSC resources. Several KSC experts were recognized for their efforts on the Smart Buyer activity with a Group Achievement Award by the Director of the NESC.

PHOTOS/KSC

Adam Pender (left) of Lockeed-Martin and Wayne Crawford of Arctic Slope Research Corporation (ASRC) install instrumentation onto a primer carrier assembly in support of the NESC Conax pyrotechnic valve testing.

Jeffrey Chrisafulli from ASRC at KSC prepares for a test firing of a pyro assembly as a part of the NESC SRB HDP Stud Hang-Up Assessment.

An Aerogel bead backfilled shroud is installed over the Space Shuttle ground umbilical carrier plate quick disconnect in preparation for cryogenic testing at KSC's launch equipment test facility.

KSC at a glance

Stephen Minute
NESC's Chief Engineer at KSC

- NESC employees at KSC: **5**
- Percent of KSC technical work force who supported NESC assessments: **4%**

LANGLEY RESEARCH CENTER

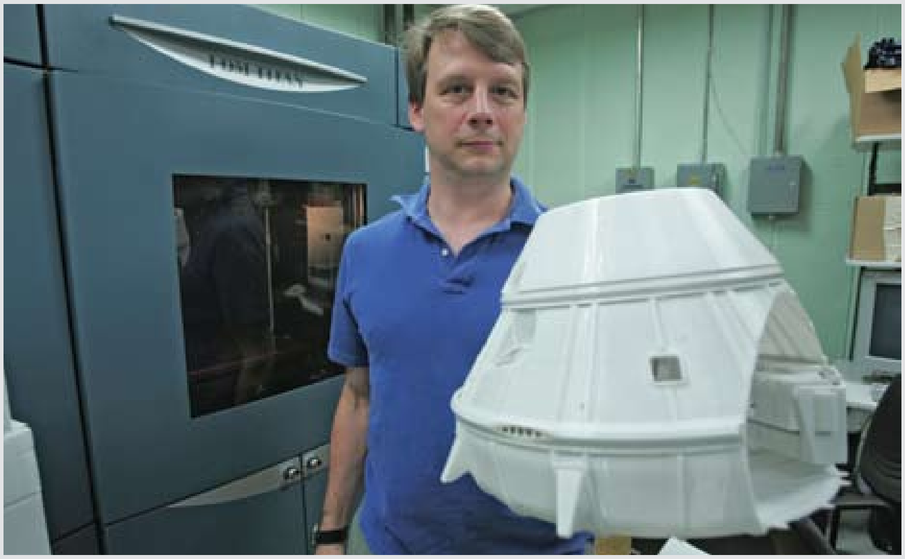
Langley Research Center (LaRC) hosts the NESC Management Office and is the resident site of the NESC Discipline Experts for Structures, Materials, and Nondestructive Evaluation. LaRC engineers and scientists contributed wide-ranging technical expertise to NESC technical assessments and investigations in the areas of structures, materials, nondestructive evaluation, flight sciences, loads and dynamics, mechanisms, guidance navigation and control, and avionics.

"Engineers at Langley Research Center really enjoy working on NESC technical assessments because of the importance to Agency missions. The experience gained by participating in these assessments makes our engineers more valuable to NASA projects being implemented at Langley."

— Dr. Charles Harris, Director, LaRC Research & Technology Directorate

Expendable Launch Vehicles

LaRC materials engineers tested pin-loaded machined rib specimens to determine anisotropic material effects on fracture characteristics of the Atlas V fuel tank in support of the Pluto/New Horizons mission launched in January 2006. For the CALIPSO mission, LaRC structural dynamics experts investigated the time-dependent dynamic response signatures of Delta-II rocket engine nozzle reinforcement band welds before flight, and LaRC radiographic nondestructive evaluation experts helped validate the accuracy of x-ray based wall thickness measurements on the Solar Terrestrail Relations Observatory (STEREO) mission Delta-II upper stage fuel tank.



LaRC

David Paddock of the Langley Mechanical Systems Branch built several rapid-prototype models of composite material CEV concepts.

Human Space Flight and Exploration

LaRC aeroelasticity engineers were instrumental in the wind-tunnel testing and data analysis leading to the Protuberance Air Load (PAL) Ramp foam removal from the Space Shuttle External Tank, and design experts from around the Center supported alternative design studies for Space Shuttle External Tank Ice Frost Ramps. LaRC avionics, systems, thermal, structures, materials, and impact dynamics engineers contributed extensively to the Constellation Program Crew Exploration Vehicle (CEV) Smart Buyer study to provide NASA with critical technical risks and design solutions. LaRC structures, aerodynamics, and impact dynamics engineers continued on with Smart Buyer follow-on studies of composite material CEV concepts, land versus water CEV landing trade-offs, and alternative CEV launch-abort system configurations.

LaRC at a glance

Dr. Michael Gilbert
NESC's Chief Engineer at LaRC

■ NESC employees at LaRC	30
■ Percent of LaRC technical work force who supported NESC assessments	11.2 %

Science and Aeronautics

LaRC's capabilities and expertise in planetary entry, descent, and landing were tapped by the Cassini/Huygens mission to Saturn to provide an independent assessment of readiness, trajectory, and residual risk for the Huygens descent to the Saturnian moon Titan. The NESC also relied extensively on LaRC materials and fracture mechanics expertise in assessing the 8-Foot High Temperature Tunnel Liquid Oxygen Run-Time Tank failure criteria, fracture margins, and recertification requirements.

LaRC

Dr. Ivatury Raju (left) and Eric Hoffman analyzed the fracture mechanics of the LaRC 8-foot High Temperature Tunnel Liquid Oxygen Run-Time Tank.

MARSHALL SPACE FLIGHT CENTER

This year, NESC personnel at Marshall Space Flight Center (MSFC) assisted in the completion of several major assessments into Space Shuttle hardware and also began supporting the Vision for Exploration. Resident at the MSFC is the NESC Discipline Expert for Propulsion, who has consulted on several projects and programs in need of propulsion expertise.

Space Shuttle Hardware

NESC personnel at MSFC completed three major assessments this year. The first two were assessments into the Orbiter's Body Flap Actuator and Rudder/Speed Brake bearing wear. The NESC team performed extensive testing of bearings to determine if previously flown bearings were fit for reuse.

Another major Space Shuttle assessment completed was the investigation into the root cause of the Holddown Post Stud Hang-Ups. This assessment involved personnel from MSFC, LaRC and KSC and involved extensive testing of flight hardware.

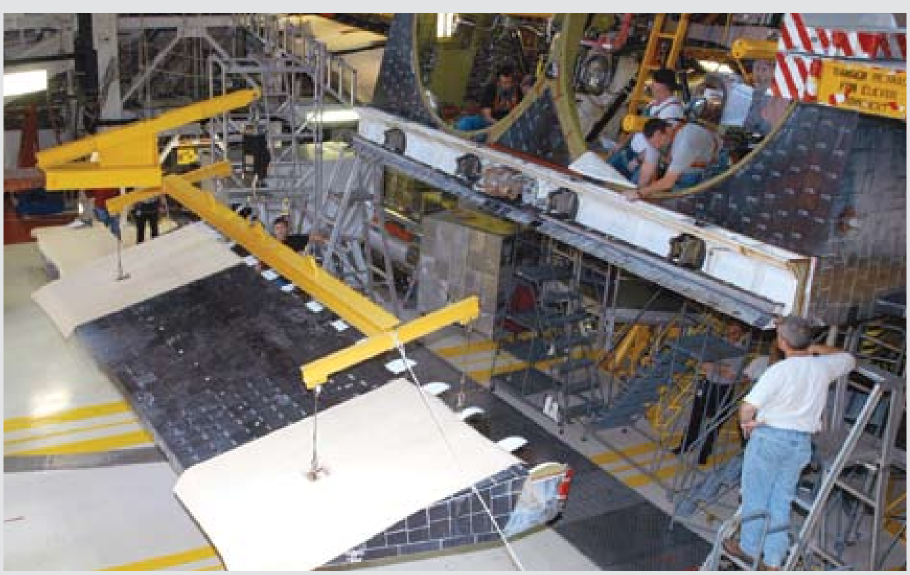
MSFC

Test engineer Alonzo Frost, prepares a CEV model for testing in the MSFC Aerodynamics Facility Tri-Sonic Wind Tunnel. Both the Baseline LAS (above left) and the Alternative LAS (above right) were tested.

Constellation Program

Aerodynamic measurements on an alternate Launch Abort System (LAS) configuration were performed in the MSFC Aerodynamic Research Facility Tri-Sonic Wind Tunnel. This effort was a part of an NESC task aimed at refining the Service Module strap-on solid motors LAS concept. This concept compared the Baseline LAS model with the Alternative LAS configuration, which was found to have significantly higher forebody axial force (drag) coefficients in the transonic to Mach 2 portion of the flight.

MSFC personnel also participated in the Agency's Smart Buyer activity and MSFC is now responsible for project management of the Ares I first stage. The Smart Buyer participants were honored by the NESC in a special ceremony.



KSC

Workers help guide the body flap toward the orbiter Atlantis for installation. NESC personnel at MSFC performed extensive testing of the body flap actuator.

MSFC at a glance

Dr. Charles Schafer
NESC's Chief Engineer at MSFC

- NESC employees at MSFC — 5
- Percent of MSFC technical work force who supported NESC assessments — 4.6 %

STENNIS SPACE CENTER

Stennis Space Center (SSC) personnel supported several noteworthy NESC efforts in 2006 planning for the future Constellation Program launch vehicles and support of the Space Shuttle operations.

In planning for the next generation of launch vehicles, the Propulsion Test Deputy Chief Engineer and senior engineers from the test contractor Jacobs Sverdrup assisted the KSC Vehicle Assembly Building (VAB) Quantity-Distance Consultation. The safety of storing five-segment Solid Rocket Motors (SRMs) in the VAB was assessed. These five-segment SRMs will be needed for the Crew Launch Vehicle. Sverdrup also took heat flux data on a motor segment disposal burn as a demonstration of future needs to support VAB safety.

The NESC Smart Buyer Team effort was supported by two experts from SSC in the area of CEV Service Module main propulsion systems. The individuals were recognized by the SSC Center Director at the SSC senior staff meeting as part of the Smart Buyer Team awards.

In a separate activity, a cryogenic helium manifold, already on-hand at SSC from foam ice/frost growth characterization work in 2005, was shipped to KSC to facilitate return-to-flight ET intertank testing.

Several Apollo-era J-2 engines and related hardware were delivered from the NASA Michoud Assembly Facility to SSC, MSFC and Rocketdyne Canoga Park. SSC's A-1 test stand will be used to test the J-2 powerhead and engine in support of the Exploration Mission Directorate's J-2X engine development activities.

In 2006, NASA SSC personnel were in recovery mode for the first part of the fiscal year in the aftermath of Hurricane Katrina, a category 5 hurricane whose eye passed directly over SSC when it made its second landfall. One-fourth of the Stennis workforce (NASA and other entities) had to seek long-term temporary housing during this period. In spite of the hardship conditions, all normal test activities resumed successfully by the beginning of 2006.

KSC

Aft segment of a solid rocket motor. NESC studied the explosive safety implications of storing five-segment SRMs in KSC's VAB in support of the Ares I and Ares V launch vehicles.

SSC

Engine test stand A-1 will be converted to support testing of the Ares I and Ares V launch vehicles.

NOAA

Stennis Space Center, located just 30 miles from downtown New Orleans, took a direct hit from Hurricane Katrina on August 29, 2005.

SSC at a glance

Dr. Shamim Rahman
NESC's Chief Engineer at SSC

- NESC employees at SSC: **1**
- Percent of SSC technical work force who supported NESC assessments: **3.9 %**

WHITE SANDS TEST FACILITY

Since its inception, the NESC has depended on assistance from the White Sands Test Facility (WSTF) in many areas. This year, WSTF personnel have supported NESC efforts for the Space Operations, Science, and Exploration Mission Directorates.

WSTF

Jayme Baas (left) and Brad Forsyth install a thruster chamber laser profilometer into an RCS thruster nozzle. The inspection tool uses the Laser Techniques Company profile mapping system and a thruster nozzle vacuum interface developed at WSTF to map the surface of the thruster chamber to detect and track growth of chips in the chamber coating.

Space Operations Activities

WSTF personnel supported NESC safety assessments of carbon and Kevlar® Composite Overwrapped Pressure Vessels (COPVs) for both the Orbiter and ISS. The WSTF COPV Team has assisted the NESC by providing expertise in the areas of Nondestructive Evaluation (NDE) and completing test and failure analyses. Activities have led to rationale for flight certification deviations allowing STS-114 and STS-121 to safely complete their missions.

WSTF personnel also supported the NESC efforts in the Orbiter's Primary Reaction Control System (RCS) thruster injector crack investigation with the development of NDE techniques. WSTF, with the NESC, developed a thruster NDE system that was chosen by the Orbiter Configuration Control Board, which funded completion of development and associated standards. WSTF is also supporting NESC activities into ice elimination from the External Tank LOX feedline.

Constellation Program

Hypervelocity impact test facilities at WSTF are being employed on the NESC Composite Crew Module (CM) pressure vessel feasibility investigation. The objective is to produce a composite design that will serve as a CM structure, provide thermal protection, and protection from micrometeoroid orbital debris. A series of tests were run to evaluate potential configurations and materials. Ballistic limits are being established for each of the different concepts. WSTF has performed a total of 48 tests to support this evaluation.

Science Mission Activities

WSTF engineers are supporting an NESC assessment into the failures of pyrotechnically operated valves. WSTF is supporting the NESC investigation of five recent pyrotechnically operated valve failures. WSTF designed and fabricated many special test apparatus that uses laser light illumination to view the pyrotechnic plume as it moves through the flow paths inside the valve itself.

WSTF

Thomas Hanson and Marene Carillo of the WSTF COPV Team are performing instrumentation check-out measurements on a 22-inch COPV to evaluate numerous NDE techniques and the data systems used to study stress/strain behavior of the Kevlar COPV's .

WSTF

Dave Hamilton
NESC's Chief Engineer at Johnson Space Center for the White Sands Test Facility

NESC Honor Awards

NESC honor awards are part of our incentive and recognition program. They are given each year to NASA Center employees, industry representatives, and other stakeholders for their efforts and achievements in the areas of engineering, leadership, teamwork, and communication.

These honorary awards formally identify individuals and groups who have made outstanding contributions to the NESC's mission and who demonstrate the following characteristics:

– Engineering and technical excellence
– Fostering an open environment

There are four NESC Honor Award categories. The **NESC Director's Award** honors individuals who take personal accountability and ownership in initiating clear and open communication on diverse and controversial issues. A key component of this award is based on the process of challenging engineering truths. The **NESC Engineering Excellence Award** honors individual accomplishments of NESC job-related tasks of such magnitude and merit as to deserve special recognition. The **NESC Leadership Award** honors individuals who have had a pronounced effect upon the technical activities of the NESC. The **NESC Group Achievement Award** honors a team of employees comprised of government and nongovernment personnel. The award is in recognition of outstanding accomplishment through the coordination of individual efforts that have contributed substantially to the success of the NESC's mission.

NESC Honor Awards, Orlando, Fla. January 31, 2006: From left: Jerry Ross (NESC Chief Astronaut/presenter), Dr. Vickie Parsons (LaRC retired), Phillip Hall (MSFC), Paul Roberts (LaRC), Steve Gentz (LaRC), Erin Moran (Swales Aerospace), Roy Hampton (ARC retired), Dr. Rebecca MacKay (GRC), David Lowry (JSC), Dr. John Lin (LaRC), Dr. Norman Knight (General Dynamics), Terresita Alston (Remtech Services), Ralph Roe, Jr. (NESC Director/presenter).

The NESC 2006 Honor Award recipients

NESC DIRECTOR'S AWARD

Mr. Raoul E. Caimi

Honored for personal determination and professional integrity in promoting the full and open discussion of the technical risks for the Pluto/New Horizons Launch Vehicle

Mr. Robert W. Cooke

Honored for exceptional technical contributions to the analysis and investigation of the Space Shuttle External Tank Liquid Hydrogen Engine Cut-off Sensor malfunction

Mr. Richard B. Katz

Honored for exceptional contributions to the Field Programmable Gate Array Reliability Technical Assessment

Dr. Henning W. Leidecker

Honored for exceptional contributions to the Orbiter Avionics Tin Whiskers Evaluation

Dr. Rebecca A. MacKay

Honored for providing exemplary technical leadership in the pursuit of root causes associated with cracking and pitting in Orbiter Injector Cracking and Rudder Speed Brake Conical Seal Panel Pitting

Dr. Stephen W. Smith

Honored for technical contributions to the Reaction Control System Injector Cracking Root Cause Analysis

NESC ENGINEERING EXCELLENCE AWARD

Ms. Terresita Y. Alston

Honored for her outstanding contributions as the NESC Academy Program Manager

Continued on next page

NESC Honor Awards, Albuquerque, New Mexico, September 26, 2006: From left: Ralph Roe, Jr. (NESC Director/presenter), Michael Dube (GSFC), David Jordan (ARC), Edward Devine (Swales Aerospace), Dr. Stephen Smith (LaRC), Raoul Caimi (KSC), Frank Zimmerman (MSFC), Jay Leggett (JSC) accepting for Michael Bay (Bay Engineering Innovations, Inc,), Steven Labbe (LaRC), Julie Kramer White (JSC), Dr. David Leckrone (GSFC), William Langford (LaRC), Paul Roberts (LaRC), Robert Cooke (SAIC), Dr. Henning Leidecker (GSFC), Leslie Curtis (LaRC), Jim Miller (LaRC), Mitchell Davis (GSFC) accepting for Richard Katz, and Dr. Charles Camarda (NESC Deputy Director for Advanced Projects/presenter).

NESC Engineering Excellence Awards continued

Mr. Roy W. Hampton

Honored in recognition for lifelong technical service and exemplary support to the structural assessment of the International Space Station European Modules that did not receive a post proof nondestructive evaluation

Dr. Norman F. Knight

Honored for outstanding contributions to the Reinforced Carbon-Carbon Impact Debris Assessment for the Return to Flight STS-114 mission

Dr. John C. Lin

Honored for outstanding contributions to the U.S. Navy in correcting flow-induced, unsteady loads on the advanced seal delivery system mini-submarine

Mr. David R. Lowry

Honored for outstanding contributions to the Reinforced Carbon-Carbon Impact Debris Assessment for the Return to Flight STS-114 mission

Ms. Erin Moran

Honored for outstanding contributions as a NASA Engineering and Safety Center technical writer

Dr. Vickie S. Parsons

Honored for outstanding technical leadership and dedication to the improvement of data mining and trending across the Agency

Mr. P. Michael Bay

Honored for outstanding technical excellence and leadership in developing the innovative concept that enabled the successful completion of the Design, Development, Test and Evaluation Considerations for Robust and Reliable Spacecraft Assessment

Mr. William M. (Mike) Langford

Honored for the innovative concept development and exemplary design and manufacturing expertise for the independent redesign of the Space Shuttle External Tank Ice Frost Ramp

Mr. Frank R. Zimmerman

Honored for exceptional technical service in the identification, development and validation of the Orbiter OV-105 Rudder Speed Brake Conical Seal Panel Repair techniques

NESC LEADERSHIP AWARD

Mr. Edward J. Devine

Honored for technical excellence and leadership that enabled the successful completion of the Control Moment Gyro 1 Failure Root Cause Analysis Technical Assessment

NESC GROUP ACHIEVEMENT AWARD

ISS Cooling Water Chemistry

Honored for the investigation into International Space Station Internal Active Thermal Control System Cooling Water Chemistry

Orbiter Rudder Speed Brake Gear Margins

Honored for the investigation into the Orbiter Rudder Speed Brake Gear Margins

Space Shuttle Main Engine High Pressure Oxygen Turbo Pump Seal Cracking

Honored for determining the root cause on the Space Shuttle Main Engine High Pressure Oxygen Turbo Pump Seal Cracking

Continued on next page

NESC Group Achievement Awards continued...

Control Moment Gyro-1 Root Cause

Honored for technical expertise and leadership in the root cause assessment of the International Space Station Control Moment Gyro 1 Failure

Design, Development, Test and Evaluation Considerations for Robust and Reliable Spacecraft

Honored for technical excellence and innovation in establishing the design, development, test and evaluation considerations for robust and reliable spacecraft

Space Shuttle External Tank Liquid Hydrogen Tank Ice Frost Ramp Redesign

Honored for exceptional technical support and innovative concept identification for the independent redesign of the External Tank Liquid Hydrogen Ice/Frost Ramps

Orbiter Rudder Speed Brake Conical Seal Panel Repair

Honored for exceptional technical support for the evaluation of the Orbiter Rudder Speed Brake Conical Seal Panel Repair techniques

Solid Rocket Booster Holddown Post Stud Hang-Ups

Honored for exemplary efforts in determining the root cause of the Solid Rocket Booster Holddown Post Stud Hang-Ups

Stardust Hypervelocity Entry Observation Campaign

Honored for outstanding technical contributions to the NESC Hypervelocity Entry Observation Campaign

NESC Employees Receive Agency Honor Awards

Several NESC employees were recognized by the Agency and received prestigious NASA medals for their outstanding contributions to the NASA/NESC mission. The presentation was hosted in September at NASA Headquarters by the NASA Office of the Chief Engineer.

NESC Recipients of NASA Honor Awards, September 18, 2006, NASA Headquarters. From left: Ralph Roe, Jr. (NESC Director/presenter), Henry Rotter (Exceptional Service Medal), Dr. Charles Harris (Exceptional Service Medal), David Hamilton (Exceptional Service Medal), Steven Labbe (Exceptional Achievement Medal), John McManamen (Exceptional Engineering Achievement Medal), Tim Wilson (Exceptional Achievement Medal), Chris Scolese (NASA Chief Engineer/presenter). Not pictured are Dr. Richard Gilbrech (Outstanding Leadership Medal) and Julie Kramer White (Exceptional Achievement Medal).

Andreas Dibbern (far left) practices as a lead investigator presenting the results of an investigation to other students who are playing the part of the NTSB panel members.

Professional Partnership and Training with the National Transportation and Safety Board

The NESC and the National Transportation and Safety Board (NTSB) have joined forces for the 2nd year to provide professional development and instruction that benefits both organizations. Through a formal interagency agreement, the NESC partnered with the NTSB to construct and deliver professional development and instruction for members of the NESC on how to manage and direct safety investigations. This collaborative effort, led by Ken Cameron, NESC Deputy Director for Safety, is an example of efforts to reach out to other professional federal organizations and learn from their experts.

Members of the NESC attended the training course and invited members from the Department of the Navy Aviation Safety community who provided a comprehensive education instruction to those who conduct independent accident investigations.

This training used actual investigators and professionals from the safety industry. The latest tools and analysis/problem solving techniques were introduced to aid participants with future investigations.

NESC Communications

The NESC website, found at: www.nesc.nasa.gov incorporates a list of NESC activities, including final reports detailing the description of the problem, findings, recommendations, and, if applicable, lessons learned. All lessons learned derived from our reports are entered through the Agency lessons learned system that serves as a communication tool for the technical community.

The NESC publishes biannual NESC Technical Updates, which include a snapshot of current NESC activities, lessons learned, recent publications and other NESC related information. These updates are also sent across the Agency to senior management officials.

More formal communication opportunities take place several times a year when the NESC Director, Ralph R. Roe, Jr., presents periodic leadership briefings to the NASA Administrator and staff. This level of communication is critical to assure the Agency that the NESC is continuing its commitment to engineering excellence and conducts value-added activities.

The NESC conducts a dynamic outreach program to increase awareness of what the NESC is, how it functions, and how the NESC resources can be accessed to solve technical and safety issues. The NESC outreach targets federal, industrial and academic communities to convey important technical information and lessons learned from our assessments.

Neil Dennehy, NESC Discipline Expert for Guidance, Navigation & Controls, (GNC) leads the instruction during the 3-day Satellite Attitude Control Systems NESC Academy Course.

NESC Academy – Learning from the Past, Looking to the Future

The NESC Academy moved forward to its second successful year of operation, presenting two, 3-day course offerings: one course in Power and Avionics and one course in Satellite Attitude Control Systems. In August 2006, the NESC Academy also began the next phase of instruction by offering online versions of the classroom courses via the NESC Academy website.

The NESC Academy was established to capture, share, and preserve the lifetimes of experiences and knowledge of NASA scientists and engineers and guide the next generation of Agency's technical staff, as they develop expertise in technical problem-solving. NESC, the National Institute of Aerospace (NIA), and CIBER partner to design, develop and deliver these courses that are led by selected NESC Discipline Experts.

Classroom Instruction

The NESC Academy offered its third knowledge-capture course at the University of Maryland from December 6-8, 2005. The course, "Power and Avionics: Learning from the Past and Looking to the Future with Robert Kichak and Colleagues," focused on electrical systems, power, avionics, and troubleshooting.

Mr. Kichak, NESC Discipline Expert for Power and Avionics, GSFC, served as the primary lecturer, discussing lessons learned, and the victim-source-coupling troubleshooting approach. The course allowed Kichak and other NASA personnel to share their experiences and problem-solving approaches not readily found in a traditional educational course.

(Above) Students in the Satellite Attitude Control Systems course. (Left) Neil Dennehy discusses the finer points with a student.

Twenty-nine students representing the electrical engineering disciplines at several NASA Centers attended the course. They received additional expert insight from Mitchell Davis, NESC Deputy Discipline Expert for Power and Avionics, and Richard Katz, specialist in digital systems for Space Flight from the NASA Office of Logic Design.

Mr. Cornelius Dennehy, NESC Discipline Expert for Guidance, Navigation, and Control, led the effort and served as the principal lecturer for the fourth NESC Academy course. "Satellite Attitude Control Systems: Learning from the Past and Looking to the Future" was held at the Jeong H. Kim Engineering Building at the University of Maryland from June 27-29, 2006. Other instructors included Frank Bauer and Richard Burns from Goddard Space Flight Center, Dr. Sanjay Garg from Glenn Research Center, and Henry Hoffman with Swales Aerospace, Inc.

Topics covered in this course included, the engineering process, lessons learned, spaceborn global positioning system and implementation of multivariable control systems. The classroom participants included technical personnel from several NASA Centers who left with a wealth of information to take back to their organization and use throughout their careers. Additional courses have been planned.

PHOTOS/NASA

Norman Helmold, from GFSC, leads a discussion of digital systems for space flight during the Power and Avionics NESC Academy course.

"..the greatest benefit of the course is that you actually get to talk to the engineers who have solved real engineering problems and go through the case studies or follow the problems that they have solved."

— Muzar Jah
Electronics Engineer, GSFC

Online NESC Academy Courses

Starting August 28, 2006, the NESC Academy offered online versions of the first three classroom courses through their website at: http://www.nescacademy.org. For those who are unable to attend the classroom version of the course, an option is to tap into the knowledge and experience of these NASA experts from a computer. The three courses available online are: Space Life Support Systems led by Hank Rotter, NESC Discipline Expert for Fluids/Life Support/Thermal, Propulsion Systems led by George Hopson, NESC Discipline Expert for Propulsion, and Power and Avionics led by Robert Kichak, NESC Discipline Expert for Power and Avionics. An online features allows participants to track their progress through the course, access knowledge capture transcripts, review lessons, and take tests associated with each specific course. As future courses are developed, each of them will be available online.

Another feature of the online course is to allow Academy participants to have a dialogue with fellow students and instructors through a forum to discuss issues and share ideas. Instructors can post information about a course and the public can read testimonials from previous participants.

"...this type of course, is great, because it gives you that systems-level understanding that you — there's no way you can get in college — of attitude control systems."

— Milton Davis
Mechanical Engineer, GSFC

Power and Avionics lead instructor Robert Kichak, NESC Discipline Expert for Power and Avionics (right) and Mitchell Davis, NESC Deputy Discipline Expert for Power and Avionics discuss a circuit design problem with a student.

"I'm fresh out of college so I don't have a lot of real world engineering experience. So this gives me an opportunity to look at case studies and look at a lot of practical engineering problems…"

— Kyle Gregory
Electronics Engineer

BIOGRAPHIES

OFFICE OF THE DIRECTOR

Ralph R. Roe, Jr.

NESC Director

Mr. Ralph R. Roe, Jr. serves as the NESC Director at Langley Research Center (LaRC). Mr. Roe has over 23 years of experience in human space flight program management, technical management, and test engineering. Mr. Roe previously held several key positions in the Space Shuttle Program, including Vehicle Engineering Manager, Launch Director, and Kennedy Space Center Shuttle Processing Engineering Director.

Timmy R. Wilson

NESC Deputy Director

Mr. Timmy R. Wilson is NESC's Deputy Director. Mr. Wilson was formerly the NESC's Chief Engineer at Kennedy Space Center (KSC). Prior to joining the NESC, Mr. Wilson served as Deputy Chief Engineer for Shuttle Processing at KSC. Mr. Wilson has over 25 years of engineering and management experience supporting the Space Shuttle Program.

Kenneth D. Cameron

NESC Deputy Director for Safety

Mr. Kenneth D. Cameron is an astronaut and NESC's Deputy Director for Safety at Langley Research Center (LaRC). Mr. Cameron was formerly an NESC Principal Engineer serving at LaRC. Mr. Cameron joined the NESC after 7 years in private industry and a career in the U.S. Marine Corps. Mr. Cameron has over 26 years of experience in aeronautics and astronautics as a Naval Aviator, test pilot, and astronaut, and is the veteran of three Space Shuttle missions: pilot of STS-37 and commander of STS-56 and STS-74.

Dr. Charles J. Camarda

NESC Deputy Director for Advanced Projects

Dr. Charles J. Camarda is the Deputy Director for Advanced Projects and is resident at the Johnson Space Center. Dr. Camarda began his NASA career in 1974 as a thermal structures research scientist at the Langley Research Center. He has over 32 years of technical and management experience in thermal structures and materials research for aircraft, spacecraft, and space launch vehicles. He was selected as an astronaut candidate in 1996 and flew aboard STS-114 as a Mission Specialist.

Jerry L. Ross

NESC Chief Astronaut

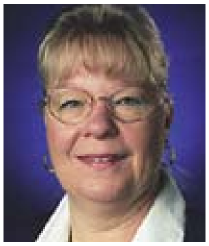
Mr. Jerry L. Ross is NESC's Chief Astronaut and is resident at Johnson Space Center (JSC). In addition to Mr. Ross' NESC assignment, he will continue in his current position as Chief of the Vehicle Integration Test Office at JSC. With over 36 years of flight, technical, and managerial experience with the U.S. Air Force and Space Shuttle Program, Mr. Ross is the veteran of seven Space Shuttle flights, including nine extravehicular activities, and was a Flight Test Engineer prior to joining NASA in 1979.

Dr. Daniel Winterhalter

NESC Chief Scientist

Dr. Daniel Winterhalter is NESC's Chief Scientist and is resident at the Jet Propulsion Laboratory (JPL). Dr. Winterhalter has over 28 years of experience as a research scientist at JPL. His research interests include the spatial evolution of the solar wind into the outer reaches of the heliosphere, as well as its interaction with and influence on planetary environments. In addition, as a member of several flight teams, he has been intimately involved with the planning, launching, and operation of complex spacecraft and space science missions.

Patricia L. Dunnington
Manager, Management and Technical Support Office

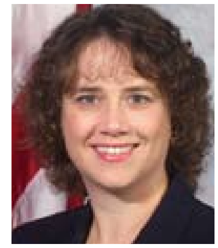


In September 2006, Ms. Patricia L. Dunnington was selected as Manager of the Management and Technical Support Office at Langley Research Center (LaRC). Prior to joining the NESC, Ms. Dunnington served as the Agency's Chief Information Officer (CIO) at NASA Headquarters. Ms. Dunnington began her NASA career in 1982 as a Presidential Management Intern. Ms. Dunnington has held several positions in the Agency, including the Deputy CIO and the CIO for the NASA Langley Research Center.

Marc S. Hollander
Manager, Management and Technical Support Office

Mr. Marc S. Hollander is the former Manager of the Management and Technical Support Office at Langley Research Center (LaRC). Prior to joining the NESC in February 2005, Mr. Hollander was the Deputy Assistant Secretary and Chief Financial Officer for the Science and Technology Directorate, Department of Homeland Security. In September of 2006, Mr. Hollander accepted an assignment with the National Institute of Health as the Associate Director for Management.

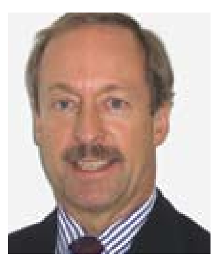
Dawn M. Schaible
Manager, Systems Engineering Office



Ms. Dawn M. Schaible is Manager of the NESC Systems Engineering Office at Langley Research Center (LaRC). Prior to joining the NESC, Ms. Schaible worked in the International Space Station/Payload Processing Directorate at Kennedy Space Center. Ms. Schaible has over 18 years of experience in systems engineering, integration, and ground processing for the Space Shuttle and International Space Station Programs.

NASA HEADQUARTERS LIAISON

Wayne R. Frazier
NASA Headquarters Senior SMA Integration Manager



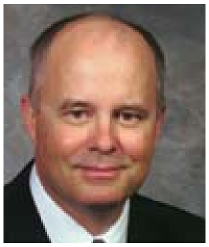
Mr. Wayne R. Frazier currently serves as Senior Safety and Mission Assurance Manager in the Office of Safety and Mission Assurance (OSMA), where he is assigned as the Liaison Officer to the NESC, the Office of the Chief Engineer, the Software Independent Verification and Validation Facility in West Virginia, and other remote activities of OSMA. He was formerly Manager of System Safety in the OSMA at NASA Headquarters and has over 31 years of experience in System Safety, Propulsion and Explosive Safety, Mishap Investigation, Range Safety, Pressure Systems, Crane Safety and Orbital Debris Mitigation.

Keith L. Hudkins
NASA Headquarters Office of the Chief Engineer Representative

Mr. Keith L. Hudkins is the representative from the NASA Headquarters Office of the Chief Engineer to the NESC. Mr. Hudkins is resident in the Office of the Chief Engineer at NASA Headquarters, where he serves as the NASA Deputy Chief Engineer. Mr. Hudkins has over 36 years of experience in systems engineering and engineering management, served as the Chief Engineer for the Space Shuttle Program, and was the Space Shuttle Orbiter Program Director.

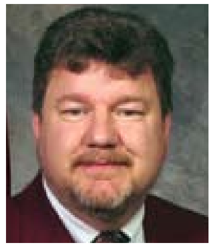
NESC PRINCIPAL ENGINEERS

Clinton H. Cragg
NESC Principal Engineer



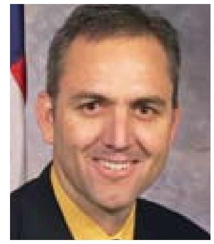
Mr. Clinton H. Cragg is a Principal Engineer with the NESC at Langley Research Center (LaRC). Mr. Cragg came to the NESC after retiring from the U.S. Navy. Mr. Cragg served as the Commanding Officer of the U.S.S. Ohio and later as the Chief of Current Operations, U.S. European Command. Mr. Cragg has over 28 years of experience in supervision, command, and ship-borne nuclear safety.

Steven J. Gentz
NESC Principal Engineer



Mr. Steven J. Gentz is a Principal Engineer with the NESC at Langley Research Center (LaRC). Mr. Gentz joined the NESC from the Marshall Space Flight Center with over 23 years of experience involving numerous NASA, Department of Defense, and industry failure analyses and incident investigations, including Challenger, Columbia, Tethered Satellite System, and the TWA 800 Accident Investigations.

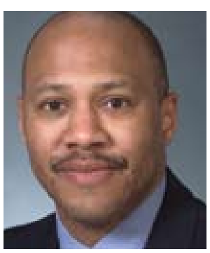
Michael T. Kirsch
NESC Principal Engineer



Mr. Michael T. Kirsch is a Principal Engineer with the NESC at Langley Research Center (LaRC). Mr. Kirsch joined the NESC from the NASA's White Sands Test Facility (WSTF) where he served as the Deputy Manager responsible for planning and directing developmental and operational tests of spacecraft propulsion systems and related subsystems. Mr. Kirsch has over 17 years of experience in managing projects and test facilities.

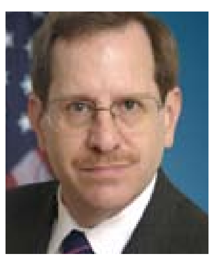
NESC CHIEF ENGINEERS

Derrick J. Cheston
NESC Chief Engineer



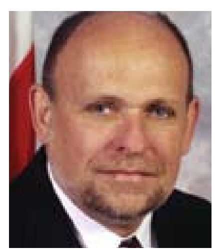
Mr. Derrick J. Cheston is the NESC Chief Engineer at Glenn Research Center (GRC). Mr. Cheston joined the NESC from his prior position at GRC as Chief of the Thermal/Fluids Systems Branch. Mr. Cheston has 22 years of experience in aerospace engineering and management, including mechanical design and testing and thermal/fluids analysis.

Dennis B. Dillman
NESC Chief Engineer



Mr. Dennis B. Dillman is the NESC Chief Engineer at NASA Headquarters. Mr. Dillman came to the NESC from the Goddard Space Flight Center (GSFC), where he chaired design reviews for major projects, including the Hubble Space Telescope Servicing Missions, the James Webb Space Telescope, and several Earth Observing System satellites. Prior to his time at GSFC, Mr. Dillman worked at the NASA Johnson Space Center managing Shuttle Orbiter sustaining engineering efforts and training Space Shuttle flight crews.

Dr. Michael G. Gilbert
NESC Chief Engineer



Dr. Michael G. Gilbert is the NESC Chief Engineer at Langley Research Center (LaRC). Before joining the NESC, he was Head of the LaRC Systems Management Office. Dr. Gilbert has over 29 years of engineering, research, and management experience with aircraft, missile, spacecraft, Space Shuttle, and International Space Station Programs.

NESC CHIEF ENGINEERS

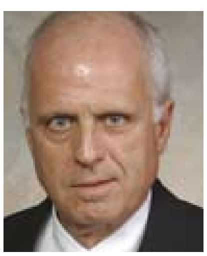
Michael Hagopian
NESC Chief Engineer

Mr. Michael Hagopian is the NESC Chief Engineer at Goddard Space Flight Center (GSFC). Mr. Hagopian came to the NESC from his position as Associate Chief of the Mechanical Systems Division at GSFC. Mr. Hagopian has over 22 years of experience in the development of space and Earth science satellites.

Stephen A. Minute
NESC Chief Engineer

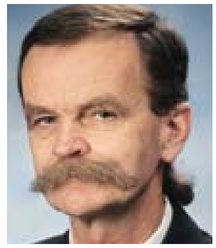
Mr. Stephen A. Minute is the NESC Chief Engineer at Kennedy Space Center (KSC). Mr. Minute came to the NESC from KSC, where he served as the Chief of the Space Shuttle Safety, Quality, and Mission Assurance Division. Mr. Minute has over 23 years of engineering and management experience in the Space Shuttle and International Space Station Programs.

Dr. Charles F. Schafer
NESC Chief Engineer



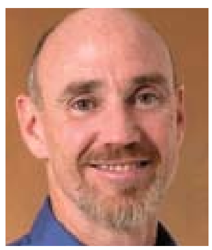
Dr. Charles F. Schafer is the NESC's Chief Engineer at Marshall Space Flight Center (MSFC). Dr. Schafer came to the NESC from MSFC where he served as the Deputy Manager of the Propulsion Research Center of the Science and Technology Directorate. Dr. Schafer has over 41 years of experience in leading research and technology activities in advanced earth-to-orbit and in-space propulsion, including work in nuclear propulsion, plasma propulsion, advanced chemical propulsion, and new chemical propellant development.

David A. Hamilton
NESC Chief Engineer



Mr. David A. Hamilton is the NESC Chief Engineer at Johnson Space Center (JSC). Mr. Hamilton came to the NESC from JSC, where he served as Chief of the Shuttle/Station Engineering Office and also as the Chairman of the Shuttle Chief Engineers Council. Mr. Hamilton has over 39 years of combined experience in NASA manned space flight programs, including Apollo, Skylab, Apollo-Soyuz, ISS, Space Shuttle, and Mir.

Brian K. Muirhead
NESC Chief Engineer

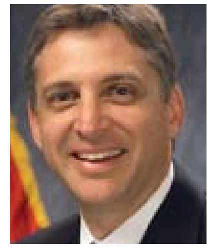


Mr. Brian K. Muirhead is the NESC Chief Engineer, as well as the Center Chief Engineer at the Jet Propulsion Laboratory (JPL). Prior to his position with the NESC, Mr. Muirhead was Chief Engineer for the Mars Science Laboratory. Mr. Muirhead has over 29 years of combined experience managing space science missions and experience in spacecraft and instrument systems design, development, integration, test, and operations, including the Galileo, SIR-C, Mars Pathfinder, and Deep Impact missions.

Dr. James F. Stewart
NESC Chief Engineer

Dr. James F. Stewart is the NESC Chief Engineer at Dryden Flight Research Center (DFRC). Dr. Stewart joined the NESC from DFRC where he served as the Dryden Exploration Mission Director. Dr. Stewart has over 41 years of management and technical experience leading missile and aircraft programs.

Dr. Dean A. Kontinos
NESC Chief Engineer



Dr. Dean A. Kontinos is the NESC Chief Engineer at Ames Research Center (ARC). Before joining the NESC, he was Chief of the Reacting Flow Environments Branch at ARC, performing and managing research and development in aerothermodynamics, arc-jet testing, and planetary entry design tools. He has over 15 years of experience in computational modeling of hypersonic flowfields and the thermal response of hypervelocity vehicles.

Dr. Shamim A. Rahman
NESC Chief Engineer

Dr. Shamim A. Rahman is the NESC Chief Engineer at Stennis Space Center (SSC). Dr. Rahman came to the NESC from SSC, where he served as the Chief Engineer for the Propulsion Test Operations Division. Dr. Rahman has 19 years of experience in the engineering of space launch vehicles and test systems, primarily in fluid, thermal, and propulsion systems. In September of 2006, Dr. Rahman was selected as the Propulsion Test Program Manager at SSC.

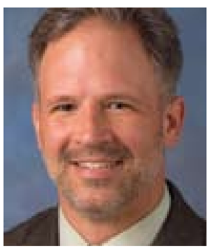
Biographies

NESC DISCIPLINE EXPERTS

Michael L. Aguilar
NESC Discipline Expert

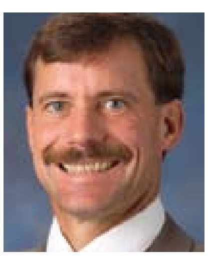
Mr. Michael L. Aguilar is the NESC Discipline Expert for Software and is resident at Goddard Space Flight Center (GSFC). Mr. Aguilar joined the NESC from GSFC where he served as the James Webb Space Telescope (JWST) Instrument Software Manager. Mr. Aguilar has over 30 years of experience on embedded software development.

Steven G. Labbe
NESC Discipline Expert



Mr. Steven G. Labbe was the NESC Discipline Expert for Flight Sciences and is resident at Johnson Space Center (JSC). Prior to joining the NESC, Mr. Labbe served as Chief of the Applied Aeroscience and Computational Fluid Dynamics Branch at JSC. Mr. Labbe has over 22 years of experience in aerodynamics research applied to programs that include Space Shuttle and X-38. In September of 2006, Mr. Labbe was selected to be the Chief Engineer for the Constellation Program Office at JSC.

John P. McManamen
NESC Discipline Expert

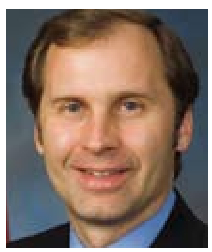


Mr. John P. McManamen is the NESC Discipline Expert for Mechanical Systems and is resident at Johnson Space Center (JSC). Prior to joining the NESC, Mr. McManamen served in a dual role capacity as the Engineering Directorate's Chief Engineer of the International Space Station and as Deputy Chief of the Shuttle/Station Engineering Office. Mr. McManamen has over 19 years of experience in mechanical systems of the Shuttle Orbiter and International Space Station.

Cornelius J. Dennehy
NESC Discipline Expert

Mr. Cornelius (Neil) J. Dennehy is the NESC Discipline Expert for Guidance, Navigation and Control (GNC) systems and is resident at Goddard Space Flight Center (GSFC). Mr. Dennehy came to the NESC from the Mission Engineering and Systems Analysis Division at GSFC, where he served as the Division's Assistant Chief for Technology. Mr. Dennehy has over 26 years of experience in the architecture, design, development, integration, and operation of GNC systems, and space platforms for communications, defense, remote sensing, and scientific mission applications.

Dr. Curtis E. Larsen
NESC Discipline Expert

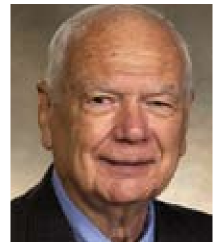


Dr. Curtis E. Larsen is the NESC Discipline Expert for Loads and Dynamics and is resident at Johnson Space Center (JSC). Prior to joining the NESC, Dr. Larsen was the Technical Discipline Manager for Cargo Integration Structures in the Space Shuttle Program's Flight Operations and Integration Office. Dr. Larsen has over 26 years of engineering experience with expertise in stochastic structural dynamics, structural safety, and probabilistic engineering applications.

Dr. Cynthia H. Null
NESC Discipline Expert

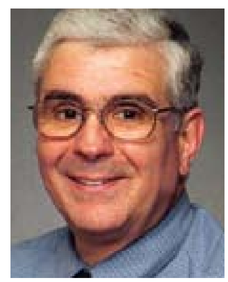
Dr. Cynthia H. Null is the NESC Discipline Expert for Human Factors and is resident at Ames Research Center (ARC). Before joining the NESC, Dr. Null was a scientist in the Human Factors Division and Deputy Program Manager of the Space Human Factors Engineering Project. Dr. Null has 20 years of experience lecturing on Human Factors, and another 15 years of experience in Human Factors applied to NASA programs.

George D. Hopson
NESC Discipline Expert



Mr. George D. Hopson is the NESC Discipline Expert for Propulsion and is resident at Marshall Space Flight Center (MSFC). Mr. Hopson came to the NESC from the Space Shuttle Main Engine Project Office, where he served as Director. Mr. Hopson has over 44 years of combined experience in Space Shuttle main engine, space propulsion, space systems dynamics, and project management.

Robert A. Kichak
NESC Discipline Expert



Mr. Robert A. Kichak is the NESC Discipline Expert for Power and Avionics and is resident at Goddard Space Flight Center (GSFC). Mr. Kichak came to the NESC from the Electrical Engineering Division at GSFC, where he served as the Division's Chief Engineer. Mr. Kichak has over 37 years of experience in spacecraft power, electrical, and avionics systems.

Dr. Robert S. Piascik
NESC Discipline Expert

Dr. Robert S. Piascik is the NESC Discipline Expert for Materials and is resident at Langley Research Center (LaRC). Dr. Piascik joined the NESC from the LaRC Mechanics of Materials Branch and the Metals and Thermal Structures Branch, where he served as a Senior Materials Scientist. Dr. Piascik has over 22 years of experience in the commercial nuclear power industry and over 14 years of experience in basic and applied materials research for several NASA programs.

NESC DISCIPLINE EXPERTS

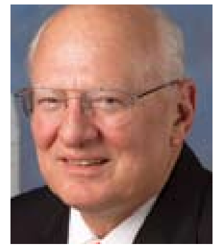
Dr. William H. Prosser
NESC Discipline Expert

Dr. William Prosser is the NESC Discipline Expert for Nondestructive Evaluation and is resident at Langley Research Center (LaRC). Dr. Prosser joined the NESC from the Nondestructive Evaluation Sciences Branch at LaRC. Dr. Prosser has over 19 years of experience in the field of ultrasonic and acoustic emission sensing techniques.

Dr. Ivatury S. Raju
NESC Discipline Expert

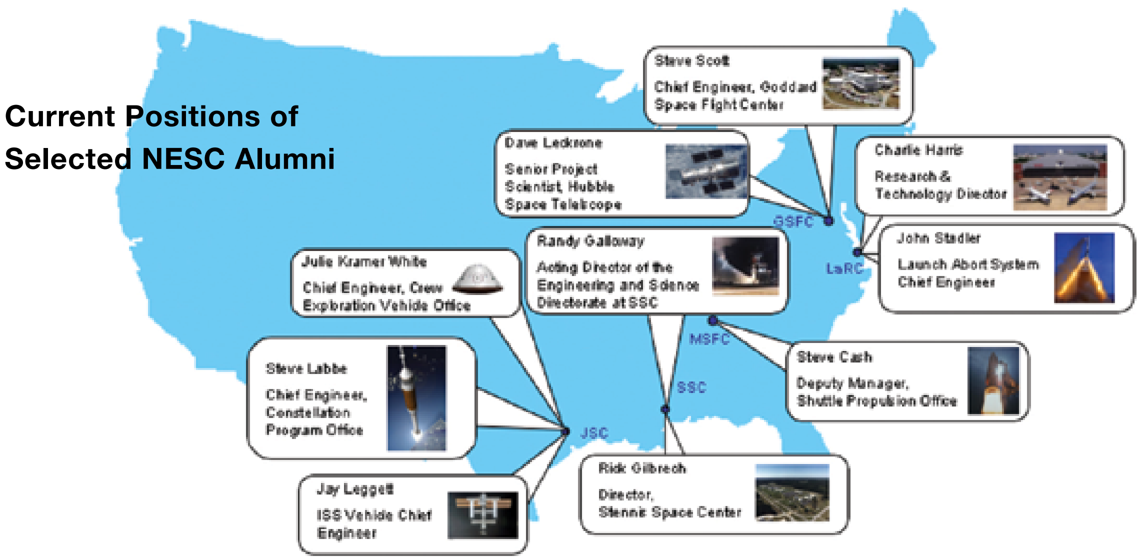
Dr. Ivatury S. Raju is the NESC Discipline Expert for Structures and is resident at Langley Research Center (LaRC). Dr. Raju was the Senior Technologist in the LaRC Structures and Materials Competency prior to joining the NESC. Dr. Raju has over 31 years of experience in structures, structural mechanics, and structural integrity.

Henry A. Rotter
NESC Discipline Expert



Mr. Henry (Hank) A. Rotter is the NESC Discipline Expert for Fluids, Life Support, and Thermal Systems, and is resident at Johnson Space Center (JSC). Mr. Rotter joined the NESC from the JSC Crew and Thermal Systems Division and the Space Launch Initiative Program, where he was Engineering Manager and the Orbital Space Plane Team Leader for life support and active thermal control teams. Mr. Rotter has over 39 years of life support and active thermal control systems experience during the Apollo, Space Shuttle, and Orbital Space Plane Programs.

NESC Alumni



Leadership Team Alumni

Frank H. Bauer
NESC Discipline Expert for Guidance Navigation and Control (2003-04)
Currently serving as the GSFC focal point for Constellation Program Systems Engineering and Integration

J. Larry Crawford
NESC Deputy Director for Safety (2003-04)
Left NESC to become Director of Safety and Mission Assurance at KSC and has since retired

Steven F. Cash
NESC Chief Engineer at MSFC (2005)
Currently the Deputy Manager, Shuttle Propulsion Office at MSFC

Dr. Michael S. Freeman
NESC Chief Engineer at ARC (2003-04)
Retired

T. Randy Galloway
NESC Chief Engineer at Stennis Space Center (SSC) (2003-04)
Currently the Acting Director of the Engineering and Science Directorate at SSC

Dr. Edward R. Generazio
NESC Discipline Expert for Nondestructive Evaluation (2003-05)
Currently a Senior Research Engineer, Research & Technology Directorate, LaRC

Dr. Richard J. Gilbrech
NESC Deputy Director (2003-05)
Left the NESC to become the LaRC Deputy Center Director and currently is the Center Director at SSC

Dr. Charles E. Harris
NESC Principal Engineer (2003-05)
Currently the Director, Research & Technology Directorate at LaRC

Dr. Steven A. Hawley
NESC Chief Astronaut (2003-04)
Currently the Director of Astromaterials Research and Exploration Science at JSC

Marc S. Hollander
Manager, NESC Management and Technical Support Office (2005-06)
Currently Associate Director for Management, National Institutes of Health

Matthew R. Landano
NESC Chief Engineer at JPL (2003-04)
Returned to his assignment at JPL as the Director of Office of Safety and Mission Success

Danny D. Johnston
NESC Chief Engineer at MSFC (2003-04)
Left the NESC to work a detailed assignment at MSFC in the NASA Chief Engineer's Office and has since retired

Michael W. Kehoe
NESC Chief Engineer at Dryden Flight Research Center (2003-05)
Currently the DFRC Liaison in the Crew Exploration Vehicle Flight Test Office at JSC

Julie A. Kramer White
NESC Discipline Expert for Mechanical Analysis (2003-06)
Currently the Chief Engineer, Crew Exploration Vehicle Office at JSC

Steven G. Labbe
NESC Discipline Expert for Flight Sciences (2003-06)
Currently the Chief Engineer, Constellation Program Office at JSC

Dr. David S. Leckrone
NESC Chief Scientist (2003-05)
Currently the Senior Project Scientist for the Hubble Space Telescope at GSFC

Dr. Paul M. Munafo
NESC Deputy Director (2003-2004)
Currently the Assistant Director for Safety and Engineering at MSFC

Stan C. Newberry
Manager of NESC's Management and Technical Support Office (2003-2004)
Left NESC to become the Deputy Center Director at ARC and has since left NASA to accept a position at DOD

Dr. Shamim A. Rahman
NESC Chief Engineer at Stennis Space Center (2005-06)
Currently the Propulsion Test Program Manager at SSC

Steven S. Scott
NESC Di°05)
Currently the Chief Engineer at GSFC

John E. Tinsley
NASA Headquarters Senior Safety and Mission Assurance Manager for NESC (2003-04)
Currently the Director of the Mission Support Division at NASA Headquarters

1. NASA/TM-2005-213231, Cloud-Aerosol LIDAR and Infrared Pathfinder Observation (CALIPSO) Spacecraft. NESC Report RP-04-01/03-001-E.

2. NASA/TM-2005-213757, AIAA Conference Paper. Guidance for Repairing Cracks in the Flowliner.

3. NASA/TM-2005-213750, Space Shuttle Orbiter Reaction Jet Driver (RJD). NESC Report RP-05-18/04-037-E.

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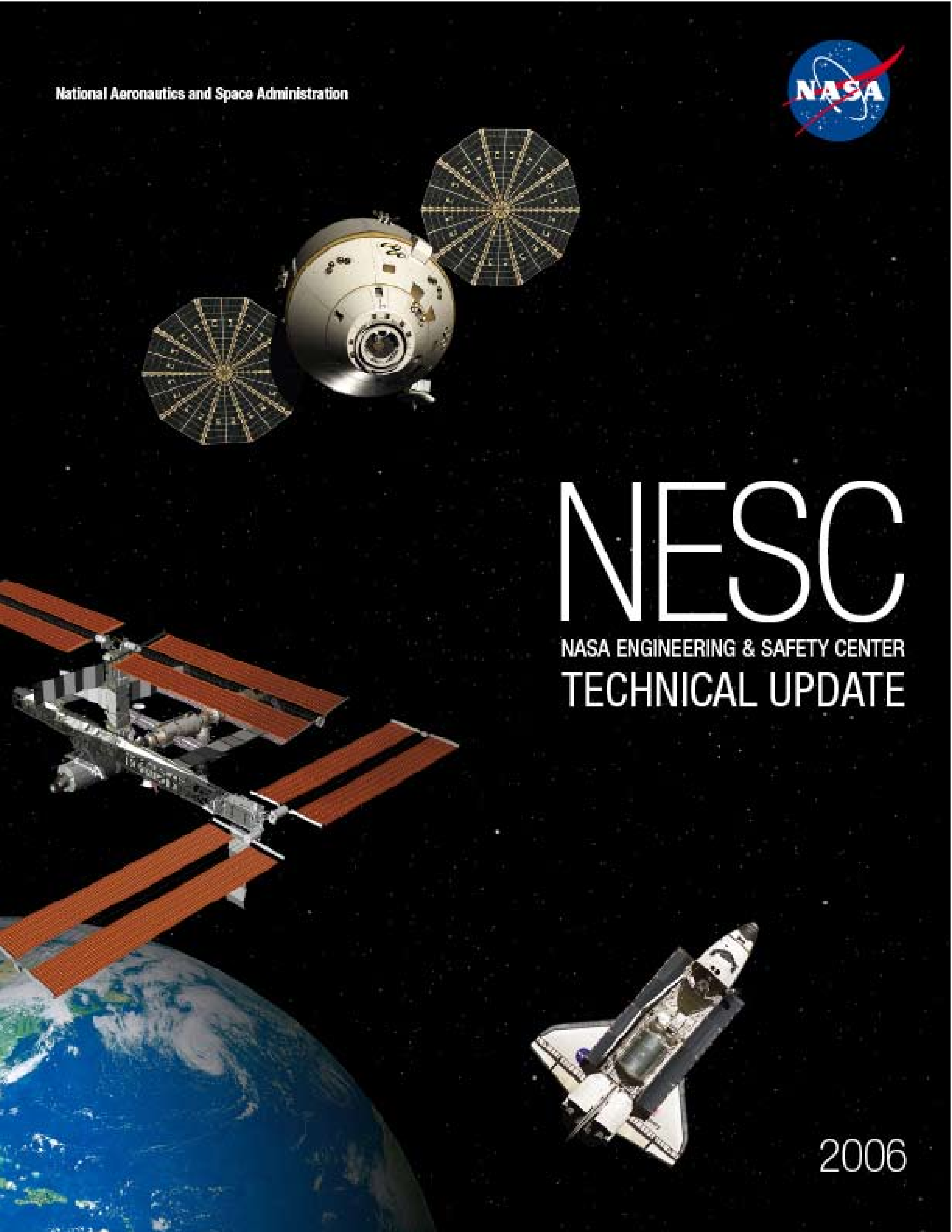

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